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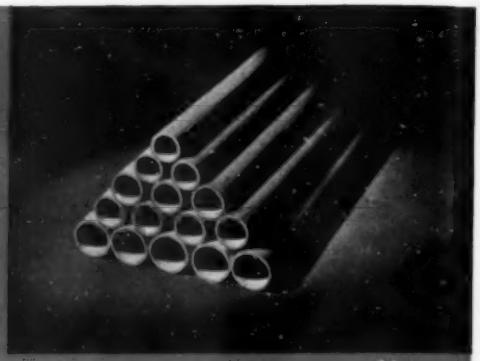

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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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PRINCIPAL CONTENTS IN THIS ISSUE:

	Page
Britain's Industrial Progress	59
Metal Spraying and Industrial Economy. By H. W. Greenwood	60
Iron and Steel Production and Development .. .. *Problems Influencing the Achievement of Future Targets.*	61–64
New Precision Light Section Rolling Mill .. .. *This new mill comprises a two stand 16-in. 3-high roughing mill and a five stand 12¼-in. finishing mill. It is designed for an average output of 75 tons of special light steel section per shift, which has been exceeded on many occasions.*	64–66
Die-casting Progress. Part II—Zinc Alloy Die Casting. By Dr. A. C. Street	67–70
The Electrolytic Polishing of Metals. By G. Tolley, B.Sc., A.R.I.C. .. *Electrolytic polishing has developed rapidly and the technique has been brought to a high standard of efficiency. The process is reviewed.*	71–74
Developments in Alloy and Special Steels. By Dr. C. Sykes, F.R.S. *Steady advances have been made in the production of alloy steels for a multiplicity of purposes involving severe service conditions. Work has proceeded with a view to controlling variables inseparable from production and use, some of which is referred to in this review.*	75–79
Copper and Copper Alloys. By E. Voce, Ph.D., M.Sc., F.I.M. .. *A survey of technical information on the production and application of copper and its alloys during 1947.*	80–85
Magnesium and Its Alloys. By R. G. Wilkinson, B.Sc. .. .. *Steady progress in the development of new applications for magnesium alloys and the restoration of those that existed before the war, is indicated in this review of technical developments.*	86–90
Aluminium Developments in 1947. By Dr. E. G. West .. .. .. *Considerable metallurgical progress has been made in the development of aluminium alloys and in fabricating technique, but in this review attention is primarily directed to applications.*	91–94
Progress in Powder Metallurgy. By E. J. Sandford, B.Sc., Ph.D., F.I.M. .. .. *Although progress during the year has not been of a revolutionary character, this review presents ample evidence of increasing interest in the application of the powder metallurgy process.*	95–99
The Cleaning of Metals. Part II—Alkaline Cleaners. By R. Groves	100–102
How to Construct a Stress-Strain Diagram by Hardness Measurements. By N. N. Davidenkov ..	102-104
New Developments in the Recording of Oscillograph Traces	104–105
Metal Conservation in Europe—Progress of Phosphating	105–106
The Behaviour of the Webs of Plate Girders	106
Some Applications of Inorganic Chromatography. By G. Robinson	107–108
A Direct Reading Microbalance for Preparative Work. By J. T. Stock and M. A. Fill	108–110
Metallurgical Digests	111–116

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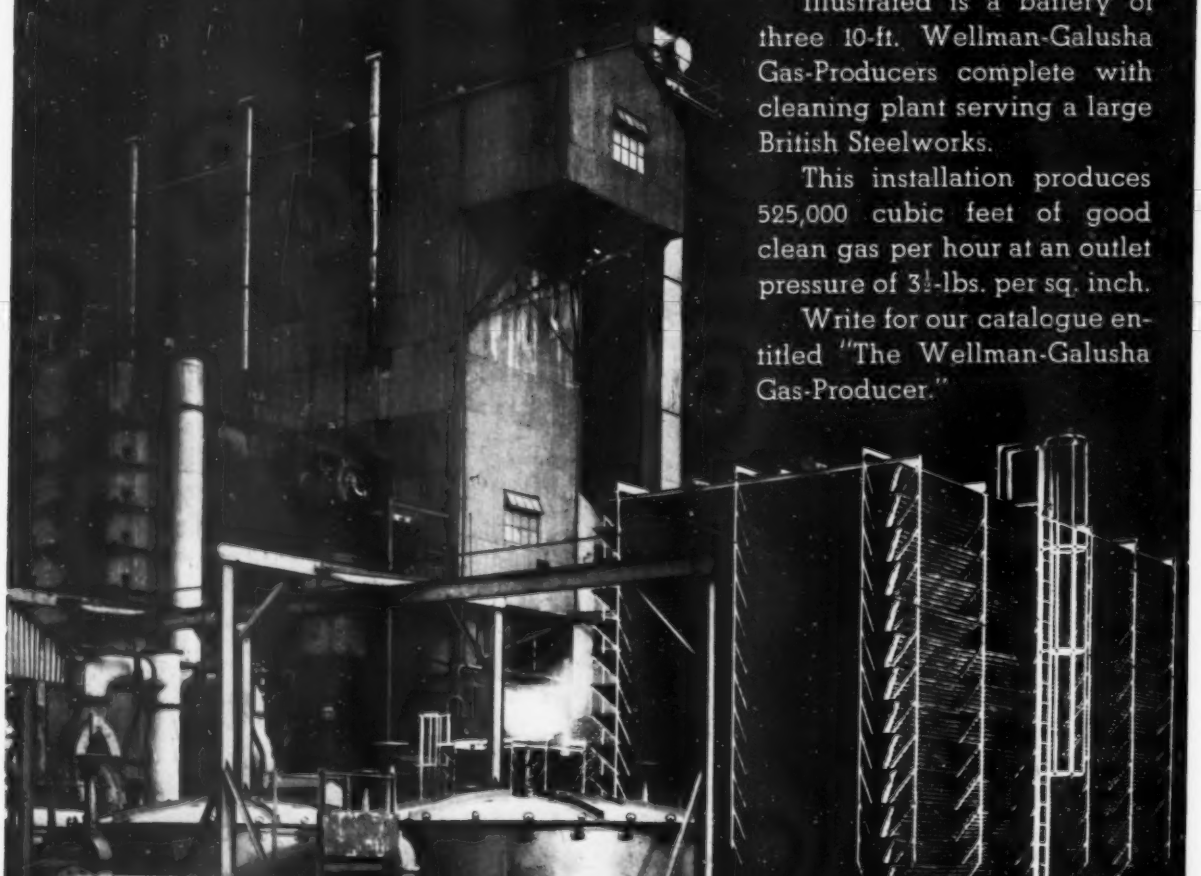

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

DECEMBER, 1947 Vol. XXXVII No. 218

Britain's Industrial Progress

THE year almost completed has been one of the most difficult in Britain's long history. At the beginning of the year it was realised by many that future progress would not be easy and the prospects for the year were not good. A great set-back was experienced in the early months when heavy snow storms brought transport to a standstill and seriously interfered with the movement of coal, causing a crisis of great magnitude. At that time the need was never greater for skill, energy and determination to promote a steady and a large expansion in production.

WE extend to all our readers our Sincere Greetings and Best Wishes for a Happy Christmastide and a Prosperous New Year

That we made an inglorious start will be generally agreed, but the results so far achieved show a degree of success beyond expectations. In March, few thought the target of 200 million tons of coal would be won from the mines and yet, if similar conditions remain during the next few weeks as in recent weeks, the target will be exceeded. The production of steel too, will undoubtedly exceed the target set for the year. Another achievement of vital importance is that exports for the year are likely to show an increase of nearly 20% on the figures for 1938, and it is interesting to note that Britain continues to predominate in the shipbuilding industry, indeed the vessels launched and on the stocks bear comparison with all other countries put together. But, while attention has been given to the progress in what may be regarded as the more vital industries, development has been proceeding at a rapid rate in other fields; thus, compared with pre-war level, electricity generated is 67% and gas output 45% higher. Production of commercial vehicles has risen by 75% and the output of agricultural tractors has increased 200%. Of other outstanding increases agriculture and the textile industry have made great progress. Thus, with problems at the beginning of the year which were almost overwhelming, Britain has concentrated on recovery to such good purpose that she has confounded her critics.

It is important to remember that increased production has been achieved while improvement and modernisation plans have been and are being carried out. Considerable new equipment has been installed in the mines, but one of the difficulties retarding output is the great distance from the shaft to the coal face in many collieries. It is well known that coal has been the main cause of Britain's production difficulties which have been intensified by the need for additional labour. However, the position is becoming more hopeful and it is certain that she will meet the principle of the Marshall plan which envisages a rise in the coal output of this country from 200 million tons this year to 250 million tons in 1951 Coal exports have been resumed and it is planned to supply Europe next year with 6 million tons, rising to 29 million tons in 1951.

Reference to developments in the iron and steel industry are given elsewhere in this issue, but figures recently issued by the British Iron and Steel Federation estimate that at least 3,100,000 tons of finished steel will be needed for direct and indirect export next year. The greater part of this total will be exported in the form of machinery and other manufactured articles by steel consuming industries. So far as direct exports of steel are concerned, the targets set by Sir Stafford Cripps are in terms of value, at September, 1947, prices, and the tonnage equivalent is dependent upon the relative proportions of higher and lower valued items. Assuming that the distribution is the same as in the third quarter of 1947, the target for finished steel is equivalent to an annual rate of 1,241,000 tons in mid-1948 rising to 1,302,000 tons by the end of the year. This is less than the 1946 export of finished steel.

The chief reason for this restriction of direct steel exports is the need to provide steel for the expansion of the metal using industries at home for the manufacture of machinery and other dollar-earning exports. For the time being this will be the steel industry's major contribution to the export drive. On the basis of such information as is available, it would appear that the supply of finished steel at a rate of 2,200,000 tons per annum will be needed to meet the export targets of the steel-consuming trades at the end of 1948.

The work so far accomplished shows that the nation can be relied on in an emergency, but what of the future? The export drive is planned to bring about a balance of payments in a period considered to be within the reach of industry. Export targets have been laid down to make up the difference after substantial economies in imports have been made. Substantial progress has been made during this year, but a further increase of 30–35% is planned for next year—a tremendous task. But it is probable that the drive will gather momentum and, when the position is reviewed at the end of 1948, the problem may not be one of insufficient production but rather one of selling the products made available.

Undoubtedly the world-wide shortage in coal, electrical plants, rolling stock, agricultural and industrial machinery is likely to last for a considerable time. But conditions abroad are hardening; buyers are becoming more selective and are making terms concerning price, quality, design and delivery data, particularly the question of delivery. Manufacturers should be as flexible as possible permitting a rapid change to meet overseas requirements.

Metal Spraying and Industrial Economy

By H. W. Greenwood

NO industrialist to-day requires reminding of the importance of economy. Here are some hints and suggestions of new or novel means of effecting important economies. Possibly wastage of metal through corrosion is one of to-day's major difficulties for on all sides shortages of essential metals provide one of the most difficult problems for the industrialist. Replacement of parts or even of essential plant is extremely difficult even if reasonably high priority is enjoyed. Everyone is well aware of the tremendous bill which annually has to be paid as the price of corrosion and rusting.

It has been suggested that iron and steel to the value of some fifty millions sterling is lost annually in Great Britain alone, and it requires but a walk through almost any works to realise how universal is the loss occasioned by atmospheric and other forms of corrosion. The vastly increased use of constructional steel work in modern times undoubtedly swells the terrible total of waste from this source. It is, therefore, all the more remarkable that known and tried methods of largely reducing this appalling loss are not more widely applied.

There is hardly a single industry that has not tried and proven the efficacy of metal spraying, especially zinc, as a protection against corrosion, and as guaranteeing a life of paint anything up to ten times the normal life and good paint applied to iron or steel without an undercoat of sprayed metal.

It is too often true that a coat of paint acts as camouflage for an area of active oxidation and deterioration due to lack of proper cleaning and preparing of the metal surface before the paint was applied. It is now generally recognised that no paint coat is entirely impervious and that if the best conditions are to be obtained, and the maximum life of the paint and its protective agency enjoyed, the preparation of the metal involves not only scrupulous cleaning by shot blasting to remove the last trace of scale or oxide, but that there must follow some further process that will provide a buffer between metal and paint, provide a really good bond for the paint and so isolate it from direct contact with the metal.

This isolating layer should possess certain characteristics; it should inhibit any oxidation or attack on the metal, it should preferably possess a certain flexibility and should under no circumstances be brittle, it should also provide a powerful key for the paint, and be free from any trace of action on that paint. This somewhat formidable catalogue of characteristics is possessed in a very high degree by sprayed zinc. It provides protection for either iron or steel in itself and to a very high degree. Its protection is of such a high order that even when the action of some attacking agent has removed the zinc from a small area, protection is still given because of the electrical relations of the iron and the zinc which ensure that corrosive influences shall attack the zinc preferentially to the iron, and so give what is called cathodic protection. If a properly prepared surface of iron or steel is zinc sprayed, and then painted with good oil paint, priming and, say, a couple of normal coats, the protection given will be superior to anything that any other treatment either by painting or by any other process can confer.

To-day such protection is of greater importance than at any previous time in our history; not only is it almost impossible to replace worn out or defective metal parts, but we cannot afford either the time or the labour such repair or replacement calls for. Nor are we likely to be able to afford it for some years to come. There is clearly indicated a policy of treating all new constructional steel work so that it will be adequately protected against corrosion; all iron and steel work that is accessible should be protected at the earliest moment, and the same applies to other materials that can undergo deterioration by atmospheric influences. The spraying of zinc can be carried out by any one of several processes available; a well known one is the Schori process using the Schori powder pistol which can apply a zinc coating by flame spraying at from 250–400 sq. ft. per hour.

A notable field of usefulness for zinc coating has been indicated by an important manufacturer of weighing machines. The moving parts, usually concealed under the platform of the machine are naturally of steel and tend to corrode and rust; this upsets the balance of the machines and leads to frequent adjustment being necessary. The application of sprayed zinc to all the moving parts has put an end to all the trouble and given much longer useful life to the machines. Another use of sprayed zinc has been in the large scoop-like scale pans used for weighing fish when landed from trawlers and fishing boats. Here the corrosive action of sea water, the abrasion by fish scales, etc., caused very rapid deterioration of the metal scoops. Spraying with zinc had an extraordinary beneficial effect and in place of a life of a very few months there is now prospect of a useful life of as many years.

The same pistol can spray most metals, and also sprays a range of plastics of outstanding properties and particular value in many industries in the form of protective coats, as for example, sulphur on asbestos board, concrete, rough cast, brickwork, where it can provide a thin flexible waterproof coat which in addition to its other outstanding properties is a first-class fungicide and a by no means negligible bactericide.

In the electrical and the food industries the new synthetic plastic Polythene has filled many important roles which have called for a material having outstanding properties as an electric insulator in which direction Polythene made an extremely valuable contribution toward the conduct of the late war. Polythene is also one of the most inert materials known, it is colourless, odourless and tasteless, it is unattacked by either inorganic or organic acids, or alkalies and so has provided an ideal lining for a very wide range of vessels used in the preparation or storage of food. Here the function of the sprayed coat is twofold: to prevent contact or contamination of the food by metal, and to preserve the metal from attack and corrosion by the food juices.

Yet another valuable part played by sprayed metal is the providing of a flexible coat as an underlayer for stove enamelling. Everyone knows how prone is enamel to crack and flake, thus exposing underlying metal to attack and corrosion. The interposition of a sprayed zinc coat before the enamel is applied prevents any cracking or flaking of the enamel coat even under the very hard use to which tubular furniture is subjected. In these days when tubular metallic furniture is becoming so widely used the use of the sprayed zinc undercoat is a means of saving very real losses due to the furniture being rendered unsightly by cracking, flaking and subsequent rusting.

Iron and Steel Production and Development

Problems Influencing the Achievement of Future Targets

Deliveries of steel to home consumers this year have been higher than last year, but production planned for 1948 is expected to supply 13 million tons for the home market and about 1¾ million tons for export. To achieve this target, difficulties will be encountered, some of which were referred to by Mr. R. M. Shone, Economic Director of the British Iron and Steel Federation, at a recent meeting held under the auspices of the University of London and the Institute of Bankers. Although the task set will be hard to achieve, it is by no means impossible and Mr. Shone described some of the efforts being made to ensure success and gave his views on Government control and public ownership, on which this article is based.

DURING the current year, the British iron and steel industry has done great work in obtaining the high tonnage from the plant capacity available, especially in view of difficulties encountered in the quantity and quality of coal supplies, transport of materials and the fact that plant modification schemes have been in progress throughout the year. The industry is confident that the target figure of 12½ million tons for 1947 will be exceeded. So far, the deliveries of steel to home consumers have been higher this year than last year and, when the final figures become available, it is confidently expected that this will be borne out for the full year.

Although production is relatively high, it is not sufficient to meet the demands. Before the war, it was customary to import steel to effect a balance between consumer needs and that produced in this country, but, apart from the fact that imports of steel are not easy to obtain, the natural desire to meet our own requirements, and if possible assist other countries with supplies, has caused the industry to proceed with modernisation and reconstruction schemes designed to raise the level of production. In 1948, for instance, the total supply for the home market is expected to be in the neighbourhood of 13 million tons, and the industry hopes to export 1¾ million tons. The home supply of steel contemplated is about 40% above the 1938 level and will be in excess of any pre-war consumption in this country.

The task undertaken by the industry is a difficult one and its achievement depends upon a number of factors the more important of which are concerned with the supply of suitable raw materials, their transport, and the problems associated with the industry's modernisation plans. Fortunately, the relations between management and labour in this industry are of a high order. Indeed, negotiations were completed this year of an arrangement under which steel furnace plants will operate continuously, that is, seven days a week in all cases where this is technically possible—which covers the majority of furnaces. This arrangement has already been of great benefit in stepping up output and, incidentally in saving fuel. The completion of this agreement at a time when the trend of events in other industries was increasingly towards closing down over week-ends, reflects the greatest credit on the farsightedness and public spirit of organised labour in the steel industry.

Of the main materials, coal, ore and scrap iron and steel predominate. Adequate supplies must be available to make the production possible. Improvement in the coal position and the information that progress is being made in improving the quality, indicates brighter prospects for the coming year. On the question of scrap, however, fluctuation of supplies may seriously handicap steel production. Every effort is being made to encourage the quick return of scrap by large industrial users of steel. The systematic collection of scrap from both large and small users of steel would do much to simplify this problem for the industry. It is understood that, next year, about a million tons of scrap is expected from Germany, which will be a great help.

While supplies of all raw materials may be adequate they must be available at the various plants to enable the objective to be fulfilled. This involves transport problems of considerable magnitude. An indication of the importance of transport to this industry was given by Mr. Shone when he said: "In five months to the end of next March, about 4 million tons of materials more than in the same period last year will need to be transported, including deliveries of an additional 830,000 tons of finished steel." Thus, raw material and transport problems may make the achievement of the target difficult, it is by no means impossible however, and every effort is being made to ensure success.

Modernisation Problems

As stated in earlier issues, the plan to modernise this industry, with a view to increased and more economic production, has been in operation since the end of the war. The Steel Board, has so far, approved definite projects covering rather more than half the expenditure contemplated under the plan—to the value of about £100 million—and work on these projects is either completed or is proceeding. As it was intended that the schemes should be initiated over a period of about five years and completed in about seven and a half, approvals are now broadly falling in line with the appropriate need to get ahead over the next few years. It should be borne in mind that the aim of the plan is to expand capacity from the 1945 level of 14 million tons to 16 million tons by about 1952. As well as this expansion, it also provides for the rebuilding of between 30% and 40% of the existing capacity. In all, the plan involves an expenditure of about £200 million at present prices.

Plant which has been brought in this year and will come in over next year relates mainly to the more modest schemes from which quick results were expected. Nothing like the full effect of the major schemes, whose construction time is longer, will be realised, except in

a minor degree, for from two to four years. These include the replacement of a large number of hand mills in the South Wales tinplate and sheet industry, by the million ton continuous strip mill which is being built by the Steel Company of Wales. There are also new blast furnaces, steelworks and the universal beam mill at Dorman Long's on the North East Coast; this latter plant has an annual capacity of 350,000 tons and will make possible striking economies in the production and use of steel joists. Also, plans have been approved for the extension of the continuous production of steel billets by a million tons. The new blast furnace plant at the Cleveland Works is estimated to cost over £4½ million. It provides for two new blast furnaces with hearth diameters of 27 ft. and an output of 7,250 to 7,500 tons of basic iron per week per furnace. There is a possibility of a further blast furnace being put in hand before the two now approved are completed.

Of the more modest schemes put into operation to bring about quick results, mention may be made of the plant improvements and developments at Samuel Fox and Company. Since the end of the war, this firm has spent well over a million pounds on a number of improvements which, together, contribute to a considerable extent of modernisation and reconstruction in all departments of the works. At the Siemens melting shop, for instance, waste heat boilers have been installed and in both this shop and the electric melting shop, fume extraction plants have been installed to enable the manufacture of lead-bearing steels. Three 75-ton basic open hearth furnaces have been converted from producer gas to crude oil firing. Transport has been eased by the installation of lime and dolomite storage bunkers and a new overhead crane, which enables materials to be more rapidly handled to and from the open hearth furnaces stage, while in the electric melting shop a simple, but effective, ingot stripper has been designed and installed to deal with "stickers."

The billet mill has been equipped with an additional Priest continuous soaker furnace with a throughput of 15 tons per hour, fired by a Morgan gas producer plant. At the same time, accuracy of temperature at the rolls is now controlled by the installation of a high speed optical recording pyrometer. Considerable alteration of the stainless sheet production plant has been effected, with an increase of 25% in the furnace capacity of the sheet mill, and an additional number of Craven and Mattison polishing machines have been installed in a new bay, which has been added to this department. The cold rolled strip department has been reorganised. The bulk of the cold rolling plant is concentrated in a new shop, which has been in operation for over 12 months; the bright bar manufacturing plant being concentrated in the old shop. Two Robertson 4-high-speeds machines are installed in the cold rolled strip department, capable of operating at 1,000/1,500 ft. per min. The output of these machines is used for high grade carbon strip, to tolerances of ± 0·0002 in., for clock and instrument main springs, feeler gauges, and razor blades. Other mills in this department are reserved for stainless strip. A battery of G.E.C. pit type electric furnaces for bright annealing in this department and 12 hardening and tempering units have been installed.

The laminated spring plant has been reorganised and new plant installed including forced air circulation furnaces, highly specialised machine tools, shot peening plant, aluminium spray plants, etc.

The fine wire department has been in production since August, 1946. Raw material in the shape of ·080 in. diameter wire is obtained from Stocksbridge in the softened and lead coated condition. It is drawn, with the necessary inter-annealing, down to sizes ·0014 in., but sizes down to ·007 in. can be drawn when required. Much of this fine work is in nickel chrome resistance wire qualities and in stainless wire in a bright annealed or bright hard drawn finish, of a tensile strength up to 140/150 tons per sq. in. The machines used are, with one exception, standard machines by Marshall Richards (9 and 11 hole), Farmer Norton (9 hole) and the Johnson Metal Co. (19 hole) and there is a Robertson rolling machine for the production of resistance tape. The one operation that is somewhat unorthodox is the incorporation of a drawing bench with the ammonia atmosphere annealing furnace, whereby annealed wire is given a light pass on emerging from the furnaces, and is then rewound.

Mention may be made of the highly integrated plant of the Workington Iron and Steel Company. Developments at these works have been steadily proceeding on a long-term plan since 1932. Some £3¼ million has been spent in modernisation and improvement schemes since that year. More recently, the White Paper on the iron and steel industry proposed the concentration of production of rails at the works of four principal makers, of which Workington is one. For this purpose, the rail-finishing banks have been extended and modernised, incorporating roller straightening and special finishing machines for rail manufacture.

Considerable progress has been made with auxiliary plant and in facilitating transport by improving the roads and railways throughout the whole works and the replacement of older type locomotives and steam cranes. A new steam boiler plant has been erected, each unit of which has a capacity of 100,000 lbs. of steam per hour at 420 lbs. pressure. Two additional units are almost completed. The electric generating station has been modernised and now has a capacity of 20,000 kw., and will be comparable in efficiency with the best modern standards.

The reorganisation of the wheel mill at Steel, Peach and Tozer's is nearing completion. The object is to raise this firm's output of railway material by 30%. Practically all the plant for the manufacture of railway wheels is new and much of it has been installed in new buildings. A new mill building has been constructed alongside and partly overlapping the existing building and a new warehouse building has also been constructed parallel to the ingot preparation and heat treatment shops. The ingot preparation shop has been extended, and a new Scriven ingot breaker and a bogie-type heating furnace installed. A continuous hardening gas-fired furnace and a vertical tempering gas-fired furnace have been installed in the heat treatment shop.

The main plant installation is the 6,000-ton Davy and United forging press; a vertical type wheel rolling mill with its ancillaries; reheating furnaces and improved handling arrangements throughout the shop. All furnaces are fired by coke oven gas piped direct from Oregreave Coke Ovens owned by the United Steel Companies. On the tyre rolling side a new heat treatment plant has been installed, with new gas-fired furnaces to cope with the increased capacity. These new furnaces comprise three rotary and three static hearth installations of the circular vertical type.

The wheel mill layout may be visualised as a capital letter E. Ingots come in at the open end of the top cross stroke, where the new Scriven ingot breaking machine is situated and also the new bogie-type reheating furnace. From there the blocks are taken to the corner of the upright stroke by a new ground type charging machine, at the moment to the 2,500-ton press, which is just about on the corner, but later they will go to the 6,000-ton press which will be substituted at a point rather further across the upright. The new reheating furnace and new wheel rolling mill are spread along the upright and serviced by a second new charging machine. The 1,500-ton dishing press, not new, but transferred from a position further up the shop, is about opposite the lowest cross stroke of the E, and is also fed by this charging machine. The dished wheels are taken off by a third new charging machine running on the same track as the second. This feeds them either direct to a new water spray treater in the lower corner of the bottom cross stroke (the new warehouse bay) from where the overhead cranes in this bay transfer them to slow cooling bins about half-way along the warehouse. Alternatively, the overhead cranes may take them direct to a transfer bogie towards the end of the shop, whence the wheels are fed into the new continuous hardening furnace and vertical tempering furnace situated at the "open" end of the cross centre stroke, together with another new water spraying machine. This bay also contains the press tool lathes which it has not been necessary to replace.

Capital Expenditure

The examples of the type of reconstruction and modernisation given are simply indications of the progress being effected throughout the industry. The plan prepared by the Iron and Steel Federation is being supported by the Steel Board involves considerable capital expenditure at a time when the Government is seeking means of reducing expenditure. It is important however, that there should be no cuts in capital expenditure on projects that are vital to improving the fundamental economic position of the country. The real need is for a more aggressive policy of modernisation and re-equipment of industries likely to improve production for export.

The steel plan, as Mr. Shone pointed out, has been partly based on the need to provide an expansion of output to meet expanding home requirements and also to improve further the net surplus of exports over imports. The total gain in exchange benefit from the expansion side of the plan would be at least £30 million a year. It is more difficult to assess the benefit from capital expenditures designed to improve the efficiency of the industry. Nevertheless, the degree of cost saving which would be achieved was one of the tests applied to all development schemes. The form the test took was to find whether new projects, after allowing for depreciation and interest, would still give a lower cost than the equipment displaced, without debiting any charge for either depreciation or interest against the existing plant. This is a severe but perfectly proper and indeed, necessary test for any capital development. In steel, no scheme has been put forward which does not pass this test. The result for the whole of the schemes so far authorised to proceed, and approximately the same figure was computed for the initial general plan, shows an average gross return on capital of just over 20% per annum as compared either with the costs at plant displaced, making no capital charges, or with current prices.

These calculations to some extent understate the return from the expenditures since they assume that the plant displaced could go on producing at its present costs, whereas in fact, it is quite certain that much of the plant could either not be used at all or would be subject to greatly increasing costs as it got older and the repair work to be done got progressively greater.

The issue facing this country at the present time, continued Mr. Shone, is whether or not it is willing to make these sacrifices for very great future gain. If we are not able to undertake this effort now, the tragic result, of course, is that, while we may maintain our standard of living for the present, it will inevitably get progressively lower and it will become even more difficult to undertake industrial development later.

Industrial Organisation

The concluding factor raised by Mr. Shone was the question of how to balance the needs of central planning with the preservation of initiative, energy and responsibility in management. With the iron and steel industry, it was realised, after the war, as essential that there should be some central co-ordination of its forward planning. The size of units was so great and the capital commitments so relatively vast, that it would have been certainly wasteful, either through not getting enough progress in some directions or through getting excessive duplication of effort, to leave the working out of schemes to separate firms without any knowledge of what their competitors were doing, or not doing, in the same field. Central planning was therefore essential, both to provide a pooling of knowledge and also to provide a machine which could both discover at the outset wasteful duplication of effort and could initiate schemes where efforts of individual companies in the first instance did not fill all essential needs. This machinery of planning worked satisfactorily and the plan was, with reasonable rapidity, produced and then in turn submitted to the Government who were able to judge it in relation to the national position as a whole and indeed to apply any other checks they thought necessary.

This type of central planning without ownership being vested in the co-ordinating body appears, from the experience of the steel industry, to have the great advantage of enabling the broad national view to be brought in to guide planning. At the same time, it leaves in the hands of individual companies who have the detailed knowledge of local conditions and specialised experience of their own trade, such a share of responsibility that they act as principals and not as hired agents in carrying out their part of the general plan.

Fundamentally, the objection to complete central ownership, of course, is that it destroys the really keen feeling of responsibility in companies and destroys the great additional safeguard provided by the need to justify efficiency directly to the public through the accounts and through the custodianship of the companies resources, as compared with the much weaker safeguard of justification through being a microscopic part of the national accounts. Arrangements of the kind I have outlined enable the central body, however it be constituted, to bring to bear a national point of view, appropriately in broad terms, and leave details, which

are of immense practical importance, in the hands of individuals who have a real and direct responsibility for success. It ensures, in short, that the load of responsibility is properly distributed so as not to clog up the centre with detail for which it is unsuited and on which it should not have to carry the risk and responsibility.

The steel industry is the main experiment in the field of public control with the retention in the individual firms of private ownership and the greater degree of managerial responsibility that goes with it as compared with public ownership of the whole industry.

It is clearly the Government's desire to encourage other industries to work along these lines of collective research, comprehensive statistics, machinery for planning and co-ordination of capital expenditures and, in fact, all the other objectives clearly set out in the Working Party Reports on many industries. This line of development will not be effective if at the same time the doctrine is advanced, as a reason for abandoning the steel experiment, that control or planning of industry cannot be satisfactorily achieved without complete national ownership.

Since the main policy for industry, outside the utility field, is to combine overall national planning with private ownership, it seems folly to consider discarding the one experiment which has established a *modus vivendi*, and which is working satisfactorily under this very set up. And in discarding the experiment, to discourage other industries which the Government hope to lead along the same course that has proved satisfactory in steel.

The steel experiment in public control should be given a fair run even if it were only because of the great importance of trying out this idea of control of industry —an idea infinitely more simple than the machinery of taking over ownership with its almost insoluble problems of demarcation between many hundreds of firms engaging in a great variety of different processes.

The degree of public control established in steel is accepted readily not as a regrettable alternative to nationalisation but because industrial planning is in itself of national advantage. Broad planning of our national economy on bolder lines than in the past may contribute great benefits to industry generally and particularly to industries such as steel which feel the full destructive force of the trade cycle; but such planning should not and need not go to such an extent that it involves central ownership, for industry is entirely unsuited to bureaucratic administration.

New Precision Light Section Rolling Mill

Developments at Darlington & Simpson Rolling Mills Ltd.

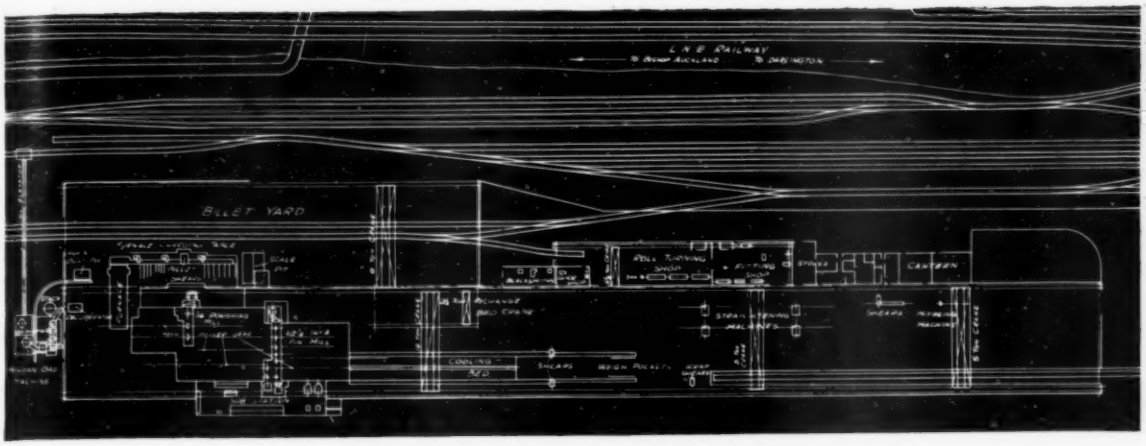
Designed for an average tonnage output of 75 tons of special light steel section per shift, this new precision mill has enabled this figure to be exceeded on many occasions; to date the record tonnage for one shift is 111 tons, and it is noteworthy that the average weight per foot of the section rolled was just over 1 lb. Brief reference is made to the Company and its new plant for the precision rolling of light sections.

SINCE the days of Henry Cort there has been persistent development in the design of rolling-mill plant and, with the introduction of many appliances for handling material mechanically during rolling, the capacity of mills has been multiplied. In the last fifty years especially, great progress has been made and in some instances the tonnage from mills in a given time has increased by as much as a hundred times. The high efficiency of this method of shaping and the ever-increasing demand for steel involve constant efforts to further development in both plant and rolling technique. For many years developments have been directed to the design of special purpose mills, and in more recent years considerable attention has been given to precision light section mills, an interesting example of which has recently been put in operation at the new West Works of Darlington & Simpson Rolling Mills, Ltd.

Although this Company was only formed in 1935, it combined the old-established firms of Darlington Rolling Mills Co., Ltd., F. R. Simpson and Co., Ltd., of Oldbury, and J. and W. Marshall, of Walsall. In addition to the rolling of steel arches, light rails and corrugated plates for collieries, which are rolled at Darlington, all these companies specialised in the rolling of light special sections for the metal window industry, the motor trade and other industries.

The development of the special section trade in this country began in 1928, when the Crittall Manufacturing Co., Ltd., joined Bolckow, Vaughan and Co., Ltd., in the formation of Darlington Rolling Mills Co., Ltd. Previous to that time the Crittall Company had depended largely on supplies from Germany, where a special technique had been developed in the rolling of light steel sections to very close tolerances. The old mills and buildings at Darlington were dismantled and a modern 12-in. section mill of German design and manufacture was installed in 1930. Later, in 1932, a second 12-in. mill, of British design and manufacture, was installed. About this time Dorman, Long and Co., having absorbed Bolckow, Vaughan and Co., joined the Crittall Company, and this position obtained until 1935 when the present Company was formed.

Since 1935 the policy of improvement and development has been continuous. In 1937 it was decided to close down the Marshall plant and install a third mill at the South Works, Darlington. This mill, which can be operated either as a 12-in. or 10-in. mill, was put into operation in 1938; it too was of British design and manufacture. Considerable improvements were also made in the North Works, which housed a 16-in. two-high rail section mill. The installation of a mechanical cooling bank and the complete re-housing of the mills and finishing department, was completed in 1939. During the war additional productive capacity was provided by the installation of a single stand 16-in. mill and cooling bank to meet the requirements of the Ministry of Supply for A.P. shot steel and joists for Bailey bridges.



Plan of the West Works showing the arrangements of the New Mill

The production of these mills is now fully absorbed in meeting the needs of collieries for steel arches, light rails and corrugated bank bars ; of the motor trade for a wide range of motor lorry rim sections, brake-shoe tees, etc. ; and of a number of industries for special sections. But, as far back as 1943, it was apparent that the use of light special sections had greatly increased, and further development was necessary to meet post-war demands. With this in view, the technical staffs of this Company, Dorman, Long and Co., and the Brightside Foundry and Engineering Co., later joined by The International Construction Co., who were appointed Consulting Engineers, collaborated in investigating the most suitable type of mill to meet this demand.

A scheme was subsequently prepared for the erection of a modern high-speed precision light section mill, with an estimated annual output of 60,000 tons. The scheme received official approval and work on a new site, adjacent to the North Works, was commenced in March, 1945. Excellent progress was made with the building and installation operations, and production trials were commenced in December 1946. During the current year, production commenced on a one-shift basis and was continued for a period of three months. The mill is now operating on a two-shift basis and as soon as raw material supplies are available, it is proposed to operate on a three-shift basis. The scheme was designed on estimates of tonnage output based on an average of 75 tons per shift ; this figure, we are informed, has been exceeded on many occasions, and up to the time of writing the record for an individual shift is an output of 111 tons. The significance of this output will be appreciated when it is realised that the average weight per foot of section was slightly over 1 lb.

The New West Works Plant

The West Works occupy about 15¼ acres of a 74-acre site, adjacent to the North Works, and comprise a billet yard 400 ft. long by 100 ft. wide, and the main mill building which is 1,000 ft. long by 100 ft. wide, with a height of 38 ft. 6 in. to the eaves. The building is of modern steel frame brick panelled type. Adjacent to the works are railway sidings totalling 2,800 yds. in length and, as will be seen in the accompanying layout, they are served by the London and North Eastern Railway between Darlington and Bishop Auckland. The works are equipped with six electric overhead travelling cranes, designed and built by Joseph Booth and Bros., and comprise a 10-ton billet yard crane ; a 15-ton mill crane ; 2- and 5-ton finishing cranes, having spans of 94 ft. 6 in. and 28 ft. 6 in. to the crane tracks. In the mill building there are also two floor-operated cranes : a 2½-ton recharge bed crane, with a span of 30 ft. 6 in. and 16 ft. 4 in. in to the track, and a 2½-ton roll shop crane with a span of 37 ft. and 16 ft. 4 in. to the track. Adjacent to the main building and on the same side as the billet yard are various smaller buildings housing the smithy, roll turning and fitting shops, etc.

The furnace charging table is located in the billet yard. It is equipped with shears for cutting 3 — 2 in. billets at a time and is fitted with run-out roller gear, driven through lineshaft and mitre wheels, for transferring billets from the shears to the re-heating furnace. The main pusher motor is of 30 h.p. The furnace, which passes through into the main mill building, is charged continuously and is so designed and operated that billets are at a suitable rolling temperature when they reach the discharging end. It is 14 ft. wide between the side walls and 50 ft. long and was built by Darlington and Simpson employees to the design of the International Construction Company.

The billet reheating furnace is gas-fired, the gas being generated in a Morgan mechanical gas producer installed by International Construction Company, coal being delivered to an adjoining bunker, by means of a 16-in. conveyer belt, direct from the railway siding. The conveyer, which has a length of 190 ft. between centres and has a capacity of 20 tons/hour when travelling, was installed by Mitchell Engineering Co. The producer gas machine is the latest type and has a capacity of 15 cwts. Coal consumption per ton of billets heated in the furnace is 1 cwt., while consumption per ton of finished material is approximately 1¼ cwts. A Newton Chambers recuperator is installed. It is of the metallic type, having 54 Newton needle elements, each 7 ft. 1 in. long, and having a capacity of 270,000 cu. ft. of waste gas per hour.

The Mill Plant

The new precision light section mill comprises a two stand 16-in. three-high roughing mill and a five stand 12½-in. finishing mill, the latter being split up into three sections : an intermediate mill comprising two three-

high stands and one two-high stand; a first finishing mill comprising one two-high stand; and a second finishing mill comprising one two-high stand. These mills were built and installed by the Brightside Foundry and Engineering Co. All the mills are direct motor-driven through gear box and pinions, with the exception of the second finishing mill which is direct motor-driven through pinions. The reduction ratio in the roughing mill is 6·15 to 1, in the intermediate mill, 3·2 to 1, and in the first finishing mill 2·28 to 1. More complete data is given in Table I.

TABLE I.—MILL DATA

	Stands	Roll-barrel length	Drive h.p.	Motor speed r.p.m.	Mill speed r.p.m.	Delivery speed ft./min.	Fly-wheel energy storage, h.p. sec. at 800 r.p.m.
Roughing Mill	Two 16-in. 3-high	3' 6"	750	400–800	65–130	275–550	10,000
Intermediate Stands	Two 12-in. 3-high	2' 6"	600	400–800	125–250	390–780	12,000
	One 12-in. 2-high	2' 6"	600	400–800	125–250	390–780	
1st Finishing ..	One 12-in. 2-high	1' 6"	600	400–800	175–350	550–1100	—
2nd Finishing	One 12-in. 2-high	1' 6"	450	175–350	175–350	350–1100	—

Rolls and Roller Bearings.—Since precision rolling at high speed was sought, the criteria in the design of these mills have been low tolerances, surface finish, lubrication, alignment, rigidity and frictionless conditions. With this in view, the rolls are machined all over and all roll neck are fitted with Skefko double row roller self-aligning bearings; thus there are four races per roll. Roll changing facilities are provided.

Roller Gear.—All the roughing and finishing mills are provided with individually motor-driven ingoing and outgoing roller gear, the motors varying on different run-out tables between ½ and 1 h.p.

Cooling Bed.—On leaving the second finishing mill the material is run on to a double-sided Morgan carry-over type mechanical cooling bed built by Davy and United Engineering Co., Ltd. It is 160 ft. long and 26 ft. 4 in. wide overall, and its two run-out tables are each fitted with 60-ton cold shears and mechanical weighing with a capacity of 4 tons. Modern straightening machines are installed.

The main electrical equipment was installed by English Electric Co.

Concentrating Production

It can justly be claimed that as a result of the enterprise and forward policy carried out by this Company, and its predecessor, there is now established in this country a branch of the steel industry, which, previously to 1928, was almost exclusively in the hands of the German steel industry. To-day, the policy of concentrating production of a highly specialised type of rolled product into one unit, has, by the quality of the product and low cost production, established the Company as the leading producer of light steel special sections.

But the success of this enterprising Company is not wholly due to the improvements and modernisation of plant and equipment, or to the new works, which have involved a capital expenditure of approximately £700,000, it is due in no small degree to the excellent teamwork of the employees and management. With the new plant and the spirit that prevails in using it great things have been made possible, and, while this Company is to be congratulated on the enterprise displayed in the modernisation scheme, it deserves as much credit for the introduction of conditions in the works which create the progressive spirit on the plant. In addition, there is a close and happy co-operation between the Crittall Manufacturing Co., as large consumers of the finished product, and Dorman, Long and Co., who are the main suppliers of the raw material.

Crofts take over Newton, Bean and Mitchell

THE Directors of Crofts (Engineers), Ltd., Empire Works, Thornbury, Bradford, announce that they have purchased the whole of the assets of the old established firm of Messrs. Newton, Bean and Mitchell.

Messrs. Newton, Bean and Mitchell were established over 50 years ago (1896) specialising in the manufacture and repair of Steam Engines, Condensing plant, Compressors, Power Transmission Accessories, etc., and have a world-wide connection. Their engines and plant are operating in most countries and have won a deservedly high reputation. The business will be carried on under the same name without interruption and with the same employees and management.

Crofts intend, after a complete re-organisation and re-equipment of the Works, to move certain of the manufactures to Dudley Hill. It is expected that the present number of employees, now about 50, will be increased to 200 in the near future.

Wellman's Change of Address

The Wellman Smith Owen Engineering Corporation, Ltd. announce that as from November 24th, 1947, the address of their Head Office in London will be:—Parnell House (opposite Victoria Station), London, S.W. 1, where they have acquired more commodious premises.

It is requested that all future communications, other than direct correspondence with the Darlaston Works, should be sent to the new address at which the Registered Office of the Corporation will now be situated.

The Telephone Numbers and Telegraphic Address will remain unaltered, except when making direct communication with their furnace construction department by telephone, the number of which is Victoria 9684-5.

So that its name will be more descriptive of its products, the high-frequency engineering company recently acquired by A. C. Wickman, Ltd. has been renamed "Applied High Frequency, Ltd." This company, previously known as Diaplastics, Ltd., produces high-frequency induction heating, dielectric heating and plastic welding equipment of a nature applicable to heat-treatment, brazing, drying, preheating and jointing processes in a wide field of industries.

Die Casting Progress

Part II—Zinc Alloy Die Casting

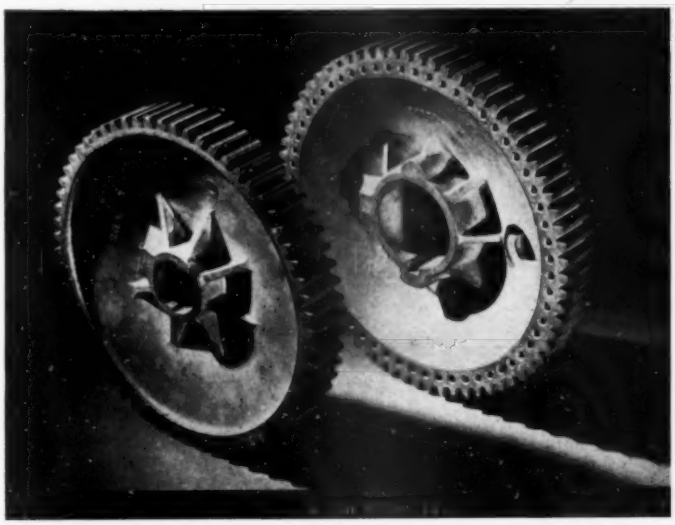
By Dr. A. C. Street

In the die-casting field the use of zinc alloys predominates and there must be very few sections of industry in which zinc alloy die castings are not regarded as essential from the points of view of adaptability and economy. Production of these castings reached their peak during the war years, and it is probable that peak figure would again be reached but for restriction of metal supplies. The present position of zinc alloy die casting is discussed.

DURING the war, Great Britain's consumption of zinc alloy for die casting rose to a peak of about 55,000 tons in 1942, compared with only 13,500 tons in 1938. The demands for die castings are so great that we could again approach that peak output during the next few years, but owing to restriction of metal supplies our consumption of zinc alloy will probably be between thirty and forty thousand tons in 1947. It has been stated that this year the U.S.A. expects to consume 250,000 tons of zinc alloy for die casting which means that per head of population, the United States will use about three times as much die cast zinc alloy as we shall.

We should find it hard to escape zinc alloy die castings these days. Many of us sleep in beds which contain zinc alloy brackets in their construction, and may be awakened by alarm clocks containing them. We may switch on an electric fire supported by zinc alloy die castings and our plated razor may be die-cast in zinc alloy. It would be easy to pursue the programme of a working day to illustrate the many uses that we all make of zinc alloy die castings in office, automobile, factory and home. It would be much more difficult to imagine a working day which did not include the use of zinc alloy, while even at the end of our labours on this earth we may come to our last resting place in a coffin fitted with several zinc alloy die castings.

After years of struggle against prejudice, the stage has been reached when most of the major users of die castings are well aware of the properties of zinc alloys; they have much experience in designing their products to take full advantage of the material and in general it can be said that they use zinc alloy die castings with confidence. The reason for any lingering prejudice is to be found in the early history of die casting. When pressure die casting began, low melting point and fluidity were the properties which determined the alloy to be used. Lead and tin base alloys were chiefly used. Zinc alloys were developed subsequently to provide extra strength and as they have a melting point of below 400° C. the pressure casting equipment of twenty-five years ago was able to cope with the material. At that time, however, the serious consequences of relatively small amounts of certain impurities in zinc alloy die castings were not appreciated and there still remained a tendency to add tin or lead to any alloy that required more fluidity when molten.



Zinc alloy die-cast gears used in a lathe. Compared with the previous processes used, die casting resulted in a saving of 850 man hours per 1,000 wheels.

Until about 1924 a zinc alloy containing tin and copper was widely used; it die-cast well and had a tensile strength of over 10 tons per square inch. At about that time, a new zinc alloy was developed containing 4% of aluminium and 3% of copper. This had still greater strength than the older zinc alloys and it came to supplant them.

Die castings in this new zinc alloy were used for many purposes, but it transpired that the alloy was not free from the defects of embrittlement, cracking and even of disintegration. Naturally, this did nothing to enhance the reputation of the zinc die casting alloys. However, during the early 1920's much work had been going on in America on the constitution and properties of these new zinc-aluminium-copper die casting alloys. It was proved that the addition of a trace of magnesium reduced the inter-crystalline corrosion, which was the major defect. Then it was proved that the zinc alloys owed their unreliability in this respect to the presence of relatively small amounts of tin, lead and cadmium which were included in the commercially available zinc, or which were picked up in the course of manufacture of the die castings.

By the early 1930's we, in this country, had reached the stage when all reputable die casters were using

Electroplated zinc alloy die castings used in automobiles. The large item is a unit of the Austin radiator grille assembly.

"four nines zinc" which was by then commercially available, thanks to the efforts of the New Jersey Zinc Co., of America, in producing a raw material, over 99·99% pure. Basing on zinc of this purity an alloy with 4·1% magnesium was widely used. This did not disintegrate in service but its properties were still not completely satisfactory. On ageing, its tensile strength and elongation were retained but its impact strength fell gradually; in addition the alloy was subject to dimensional changes.

Two other zinc alloys soon became available; compositions of which are given in Table I. Before 1939 the "Mazak 2" alloy was still favoured by most concerns, the "Mazak 5" alloy was being used in increasing amounts, but the use of "Mazak 3" was not widespread. By the beginning of the 1939 war it had been realised that the "Mazak 3" alloy was the most reliable for precision castings and stressed components since in the virtual absence of copper it was stable with respect to retention of mechanical properties and dimensions. Slight reduction of tensile strength and increase in percentage elongation were the most significant results of ageing.

In 1935, Imperial Smelting Corporation Ltd., approached Government Designs Departments with a view to obtaining approval of the alloys to the Mazak specifications for the production of components used in the manufacture of Government stores.

TABLE I.
ZINC DIE-CASTING ALLOYS; COMPOSITION BY WEIGHT.

Alloy	Copper	Aluminium	Magnesium
	%	%	%
Mazak 2	2·5–2·9	3·9–4·3	0·02–0·05
Mazak 3	0·03 max.	3·9–4·3	0·03–0·06
Mazak 5	0·75–1·25	3·9–4·3	0·03–0·06

The balance consisting of zinc of purity specified as greater than 99·99%.

Designs Department were anxious to investigate the claims made by the company for Mazak as they realised that its low cost and high speed of production, coupled with its adaptability to the production of intricate shapes to close dimensional limits, made die casting in zinc alloy a process invaluable for the meeting of large quantity requirements. Moreover, the stability and good corrosion resistance claimed for these high purity zinc alloys was an added advantage.

The initial tests which were carried out showed that there was good justification for the claims made for the alloys of Mazak specification, with very low impurity contents and close composition limits, and they were approved.

In 1938 the range of applications of pressure die castings in Mazak Alloy was considerably increased and various test specimens of certain ammunition components were die cast and supplied for extended tests to be carried out at Royal Ordnance Factories. The castings were submitted to rough usage and filling tests, after which full-scale firing tests were put in hand. These tests proved so satisfactory that contracts were immediately placed for limited quantities of grenade fuse components to be produced by this process. When war was declared in September, 1939, designs for die casting in zinc alloy several types of ammunition components had already been approved, and samples had been thoroughly tested.

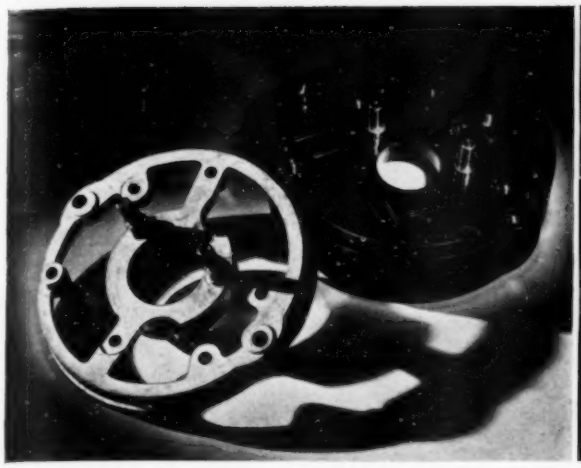
At that time, no official specification for zinc die casting alloys existed in this country, though it had been agreed to concentrate production on the copper-free alloy—Mazak 3. Early in 1941, steps were taken to issue British Standard Specifications and in December, 1941, B.S. 1003 and B.S. 1004 were published. B.S. 1003 covered the maximum limits of impurities which could be tolerated in the high purity zinc used for alloy manufacture. B.S. 1004 specified the composition of two alloys, designated A and B, to which Mazak 3 and 5 conform respectively. The composition of die castings was also covered, together with conditions for their manufacture and inspection. Table II shows the permissible limits of composition of the two alloys, while Table III shows those to which die castings must conform.

TABLE II.—CHEMICAL COMPOSITION OF ALLOY INGOT METAL.

Element	B.S. 1004/A	B.S. 1004/B
	%	%
Aluminium	3·9–4·3	3·9–4·3
Copper	0–0·03	0·75–1·25
Magnesium	0·03–0·06	0·03–0·06
Iron	0–0·075	0–0·075
Lead	0–0·003	0–0·003
Cadmium	0–0·003	0–0·003
Tin	0–0·001	0–0·001
Zinc	Remainder	Remainder

TABLE III.
CHEMICAL COMPOSITION OF DIE CASTINGS IN ZINC BASE ALLOYS.

Element	B.S. 1004/A	B.S. 1004/B
	%	%
Aluminium	3·9–4·3	3·9–4·3
Copper	0–0·10	0·75–1·25
Magnesium	0·03–0·06	0·03–0·06
Iron	0–0·10	0–0·10
Lead	0–0·005	0–0·005
Cadmium	0–0·005	0–0·005
Tin	0–0·002	0–0·002
Zinc	Remainder	Remainder



A zinc alloy die casting for the distributor base of a motor-car engine. The die casting is covered with injection moulded plastic, shown in the right-hand view.

At the same time, an analytical sub-committee was set up to advise on methods of analysis, and in November 1942, B.S.S. 1005 was published, covering details of sampling and chemical analyses, of these alloys. Subsequently, methods for polarigraphic and spectographic analysis were covered by the issue of B.S. 1225.

In order to conserve supplies of virgin metal during the war it was thought desirable to reclaim redundant zinc alloy die castings and scrap as secondary zinc alloy for the production of certain less critical, but essential, civil requirements.

In 1943, to safeguard the high standards of purity set by B.S. 1004, a war emergency specification, B.S.1141 was drawn up to cover this material. B.S. 1141 laid down that the zinc alloy shall be manufactured by re-melting clean zinc alloy die castings only, the use of swarf, dross and like materials being prohibited; it also drew attention to the unsuitability of the alloy for applications where some degree of deterioration might have serious consequence.

TABLE IV.
CHEMICAL COMPOSITION OF SECONDARY ALLOY TO B.S. 1141.

	%
Aluminium	3·9–4·3
Copper	Not more than 1·0
Magnesium	0·03–0·06
Iron	Not more than 0·1
Lead	Not more than 0·007
Cadmium	Not more than 0·005
Tin	Not more than 0·005
Zinc	Remainder

It was thought that this alloy, the composition of which is shown on Table IV, would by now have been purely of historical interest, but the present short supply position of high purity zinc has temporarily given B.S. 1141 a new lease of life for the making of tags and other parts which are only lightly stressed.

It is likely that most die casters will keep their production to alloy B.S. 1004A, until an even better alloy is made available. There is also definite demand for B.S. 1004B, on account of its comparatively greater hardness and strength, and it is interesting that in Switzerland production appears to be concentrated on Alloy B. In this country its use is sometimes preferred for metal toys and for gears, where its greater hardness is advantageous.

Zinc alloy die castings as used in a car trafficator. The top views show that a translucent plastic is moulded over a die-cast insert. The pair on the right foreground show a brush holder where the zinc alloy insert is used to carry the current, while the plastic portion, moulded on to the die casting, provides insulating properties. The switch arm on the left is another example of zinc alloy and plastic in combination.

Table V shows a comparison of the mechanical properties of the two alloys, firstly as obtained in 1938 and then as obtained in 1944. The striking improvement in properties is accounted for entirely by advances in die design and casting technique.

TABLE V.
MECHANICAL PROPERTIES OF ZINC-ALLOY DIE CASTINGS AFTER VARIOUS AGEING TREATMENTS.

	B.S. 1004/A-Type Alloy		B.S. 1004/B-Type Alloy	
	Properties reported in 1938	Improved properties reported in 1944	Properties reported in 1938	Improved properties reported in 1944
Tensile Strength (tons per sq. in.):—				
As cast	18·0	18·3	20·3	21·25
Aged at 95° C. (dry air) for 2 years	13·30	13·44	14·3	15·71
Aged at room temperature for 7 years	15·45	15·01	16·34	17·10
Aged at room temperature for 10 years	15·22	Not yet available	16·34	Not yet available
Tensile Elongation (% on 2 in.):—				
As cast	5	10	3	7
Aged at 95° C. (dry air) for 2 years	11	17	2	13
Aged at room temperature for 7 years	10	16	6	15
Aged at room temperature for 10 years	9	Not yet available	6	Not yet available
Impact Strength (ft.-lb.):—				
As cast	20	43	18	48
Aged at 95° C. (dry air) for 2 years	23	36	4	7
Aged at room temperature for 7 years	24	41	17	42
Aged at room temperature for 10 years	24	Not yet available	16	Not yet available

Before the present zinc alloys were established hundreds of zinc alloy combinations were tested. There is reason to doubt whether we can expect very spectacular developments in new zinc alloys. There is still a need for a pressure die casting alloy which will solder; since the alloys now employed contain about 4% aluminium, soldering can be done only by somewhat laborious means and thus many items used, for example, in the electrical trade, cannot be die cast.

During the last few years, a number of tests have been carried out by die casters in this country, using zinc alloy compositions that are claimed to be solderable. Though naturally it would be a useful step forward if a really suitable solderable alloy could be put into the die casters' repertoire it is felt that no such alloy has yet been produced. Those alloys that have been tried suffer from weakness at elevated temperatures and, still more serious, they are liable to spoil the properties of the present alloys if contamination occurs. Bearing in mind that solderable alloys possess the same appearance as standard alloys it is reluctantly, but strongly, felt that so far no solderable alloy can be recommended to users.

It is known that zinc alloy die castings are not intended for continuous service at elevated temperatures. For a stressed component in zinc alloy to B.S. 1004A, the temperature should certainly not exceed 100° C. Castings in alloy B. should not be used for temperatures above normal, since they are liable to slight reduction in impact strength on ageing and that process is hastened by elevation of temperature.

Information is less widespread about the effect of subnormal temperatures. Reduction in temperature causes no marked deterioration in tensile strength. Impact strength, however, is affected as will be seen from Tables VI and VII. It must be appreciated, nevertheless, that even at minus 40° C. the impact strength of zinc alloy is still greater than that of ordinary cast iron and is quite comparable with that of cast aluminium alloys at ordinary temperatures. On restoration of normal temperature the impact strength comes back to normal. Providing that this effect is allowed for in designing articles which are subjected to subnormal temperatures, zinc alloy can safely be used, as is borne out by the adoption of the alloy for munition components which had to withstand low temperatures.

TABLE VI.
EFFECT OF TEMPERATURE ON PROPERTIES OF B.S. 1004/A.

Temperature	Tensile Strength	Elongation	Brinell Hardness	Impact Strength
°C.	Tons per sq. in.	% on 2 in.	Nos.	Ft.-lb.
−40	20·0	3	91	2
−20	19·5	4	87	4
0	18·4	6	82	23
21	18·3	10	82	43
40	16·0	16	68	42
95	12·7	30	43	40

TABLE VII.
EFFECT OF TEMPERATURE ON PROPERTIES OF B.S. 1004/B.

Temperature	Tensile Strength	Elongation	Brinell Hardness	Impact Strength
°C.	Tons per sq. in.	% on 2 in.	Nos.	Ft.-lb.
−40	21·83	2	107	2
−20	22·05	3	104	4
0	21·6	6	99	41
21	21·2	7	91	48
40	19·0	13	89	46
95	15·5	23	62	43

Measuring the Variables in Resistance Welding

THE British Welding Research Association announces the publication of a first interim progress report on researches made on the measurement of the main variables in resistance welding machines by their FR.5 Committee on Development of Devices for Measuring Current, Pressure and Time in Resistance Welding.

This report describes instruments that have been specially developed for the measurement of the main variables in resistance welding machines. The work was initiated in November, 1943, when it became clear that laboratory research in resistance welding could be of direct value to industry only if its results could be applied in shop welding practice by means of simple and accurate instruments.

Part of the work of the resistance welding committees has been to determine optimum welding conditions for various processes and materials, and the time has come when definite recommendations are being made by the Association in this direction—recommendations that are based upon most exhaustive laboratory tests. The value of such recommendations cannot be over-estimated when due attention is given to the fact that each user of resistance welding is at some time or other faced with the necessity of attempting to standardise or rationalise machine settings in his own shop, though he usually finds it easier to do this on a quite arbitrary basis. The British Welding Research Association is however, attempting whenever possible, to recommend machine settings on an absolute basis, i.e., the value of the welding current in amperes, the welding time in cycles, and the welding pressure in pounds per square inch. The optimum values recommended are such that a high degree of consistency of weld strength and quality can be attained, and the effects produced by fluctuations in mains voltage or air pressure supply thereby reduced to a minimum. Without suitable robust instruments of sufficient accuracy and simplicity, welding machines working under mass production conditions cannot be quickly and easily set to give the required optimum conditions. The absence of such instruments for resistance welding purposes obviously necessitated the attention of a Committee of the British Welding Research Association.

Commercial instruments are already available for the measurement of static pressure, but the measurement of "dynamic pressure"—a problem rather more associated with laboratory experimental work than with production—is still receiving the attention of the Committee.

It has already been shown that with the use of the instruments developed, it is possible to pre-set a spot welding machine in a very short time with such an accuracy that the resultant weld strength can be predicted to within 5%.

The development of the various instruments that have had the attention of the Committee has been carried out largely in the works of the various committee members, and special thanks are due to the active help and co-operation of Messrs. Everett Edgcumbe Ltd., Johnson Matthey and Co. Ltd., and the British Thomson-Houston Co. Ltd.

This interim progress report is to be published in the official organ of the B.W.R.A. (the *Welding Research* supplement of the Transactions of the Institute of Welding) for December, 1947, and reprints of this report will also be available on application to the British Welding Research Association, 29, Park Crescent, London, W.1.

The Electrolytic Polishing of Metals

By G. Tolley, B.Sc., A.R.I.C.

Although relatively a recent development, investigations on electrolytic polishing of metals have proceeded rapidly and have brought the technique to a high standard of efficiency. Probably the most frequent application is in finishing for appearance, where brilliance and colour tone can be achieved to exceed that possible by mechanical methods. The best results are obtained on shaped parts and generally, the process is more economical when applied to supplement mechanical polishing. Attention is directed to the application of the process in metallography as well as in the finish of products.

DURING the last ten years or so a great deal of attention has centred upon the methods of polishing metals by electrolytic means. It was Jacquet, in 1935, who first demonstrated that copper could be given a mirror finish by anodic treatment in orthophosphoric acid solution,[1] and it is largely due to his work that electrolytic polishing is to-day a reliable process for research laboratory or industrial production line. The electrolytic method possesses several distinct advantages over the mechanical method of polishing and it is the purpose of this review to draw attention to these advantages and also to survey the many reliable electrolytic methods of polishing metals. Although investigations on electrolytic methods have proceeded rapidly and have brought the technique to a high standard of efficiency, there is still a marked reticence to their widespread use either for preparation of metallographic specimens or for the finishing of commercial products. It is clearly desirable that tedious mechanical methods of polishing should, wherever possible, be replaced by the cheaper and more easily controlled electrolytic method.

The fundamental theory of the mechanism of electrolytic polishing has not advanced so rapidly as practice and a complete explanation of the many known facts cannot be given. However, it has been shown by Jacquet[2] and Elmore[3] that the polishing action is due to the anodic solution of the high points on the surface of the metal in preference to the low valleys. This preferential solution is explained by the formation of a liquid film which covers the surface of the anode evenly so that the high points of the surface are separated from the bulk of the electrolyte by a thinner layer than the valleys. The resistance across the thinner places of the film, i.e., the ridges, is smaller than across the thicker places, hence the high points of the surface will tend to dissolve first, with only a slight solution of the lower points. This theory explains the general action of electrolytic polishing although a more detailed exposition is needed especially with regard to the formation of the liquid layer and its mode of action in inducing preferential solution before a satisfactory explanation of the numerous special cases can be given.

The applications of electrolytic polishing can conveniently be dealt with by considering separately its use in metallography and industry.

Metallography

There are obvious advantages over mechanical means of polishing. These may be listed thus :—

(1) It is possible to obtain reproducible surfaces.

(2) All scratches are ultimately eliminated from the surface of the specimen.

(3) Much more rapid than the mechanical method and does not require the constant attention of the operator.

(4) It is possible to polish specimens in batches by using several cells.

(5) The surface produced is free from deformation and the Beilby layer and is, therefore, the true surface. This is especially valuable when dealing with soft metals such as lead, tin and their alloys.

It should be noted that electrolytic polishing does not entirely replace mechanical polishing, but rather supplements it. It is still necessary to prepare a reasonably smooth surface before anodic treatment, and as a general rule careful preliminary mechanical polishing means a better final polish. Usually a mechanical polish to 000 emery gives a very satisfactory preliminary surface.

There are two main types of electrolyte used for polishing metals in the laboratory—both due to Jacquet. They are based on :—

(1) Orthophosphoric acid, either in aqueous or alcoholic solution.

(2) Perchloric acid, in an organic solvent such as acetic anhydride, acetic acid, acetone or ethyl alcohol.

Phosphoric acid is used for copper, copper-base alloys, zinc, magnesium, nickel and cobalt. The voltage is the controlling factor in the use of this electrolyte. Perchloric acid electrolytes have to be prepared and handled very carefully as there is a great risk of explosion. When in use they should not be allowed to come into contact with organic matter or bismuth alloys. When mixing, the temperature should be kept below 20° C. and should be kept below 30° C. when in use. Electrolytes based on perchloric acid have been used to polish lead, tin, cadmium, aluminium and steel.

Methods for Various Metals

Aluminium and its alloys. For aluminium Jacquet[4,5] used : Acetic anhydride 785 ml. ; Perchloric acid (S.G. = 1·48) 215 ml., with a voltage of 50–100 v., a current density of 3–5 amps./dm.^{2} and a temperature of 40–50° C. Under these conditions about 0·004 mm. of metal is dissolved per minute, and a specimen, given a preliminary polish on the finest emery, takes about 15 minutes to finally polish. De Sy and Haemers[6] used perchloric acid and ethyl alcohol for aluminium and aluminium alloys. They prepared their specimens on 0 emery paper and used a cathode of 18–8 stainless steel placed horizontally 6–10 cm. below the anode. The

solution near the anode was stirred to prevent a local rise in temperature and the temperature of the electrolyte was kept below 35° C. by water cooling. The voltage was 110–220 v. and the time of polishing was 10–20 secs. They give the following useful table (Table I) summarising the behaviour of several aluminium-base alloys. They were also able to polish Y-alloy, Duralumin, and Anticorodal. Those alloys containing silicon are likely to be troublesome.

TABLE I.—ELECTROPOLISHING OF ALUMINIUM ALLOYS
(After De Sy and Haemers)

Alloy	Current Density	Remarks
Aluminium-copper up to 33% copper.	1–2 amps./cm.^{2} for 20 secs.	$Cu\ Al_2$ acquires a dark colouration.
Aluminium-manganese up to 20% manganese	2–3 amps./cm.^{2}	$Mn\ Al_4$ becomes light grey colour.
Aluminium-nickel up to 30% nickel.	1–2 amps./cm.^{2} for 20 secs.	Alloy constituent tends to stand slightly in relief.
Aluminium-iron	3–4 amps./cm.^{2}	$Fe\ Al_3$ is coloured brown.
Aluminium-titanium	11·5 amps./cm.^{2} for 20 secs.	$Ti\ Al_3$ easily distinguished.
Aluminium-magnesium to 15% magnesium	1–2 amps./cm.^{2} for 10 secs.	Polish to 600 paper instead of 0 prior to electrolytic polishing.
Aluminium-zinc	1–2 amps./cm.^{2}	$Zn_2\ Al_3$ is distinguished.
Aluminium-silicon	Method is unsuitable because of rapid attack on the silicon-rich constituent.	
Aluminium–2% Fe–2% Ni.	Not given.	$Ni\ Al_3$ and $Fe\ Al_3$ difficult to distinguish.
Aluminium–20% Cu–1·5% Fe.	Not given.	$Fe\ Al_3$ distinguishable from $Cu\ Al_2$.
Aluminium–4% Fe–1% Si	Not given.	Si readily distinguished from $Fe\ Al_3$.

The Aluminium Company of America[7] uses dilute fluoboric acid (HBF_4) as electrolyte and the specimen is given a preliminary polish by using No. 600 alundum grit. This method is particularly useful in detecting the precipitated phase in Al–Cu alloys when they have been precipitation hardened.

Koch and Lehmann[8] investigated, by means of the electron microscope, aluminium that had been electrolytically polished by means of the Brytal, Alzac and Jacquet methods, and found that an oxide film was definitely present on the first two, but their results for the Jacquet method were inconclusive. Nelson[9] on the basis of electron diffraction studies concludes that there is an oxide film upon electrolytically polished aluminium, but Morize, Lacombe and Chaudron,[10] using solution potential measurements state that the Jacquet method gives an aluminium surface free from oxide.

Copper and Brass. Originally Jacquet polished copper in an electrolyte containing 500 gm./litre phosphoric acid[1] but he now finds that 900 gm./litre is preferable.[11] The cell voltage is 1·5–2 v. and the time of polishing is 15–30 minutes. This method can also be used to polish a wide range of copper-base alloys. Rodda[12] used a solution containing 200 gm./litre CrO_3 in water, using a C.D. between 10 and 50 amps./in.^{2}. The temperature of the solution should be below 30° C. This solution does not appear to be so successful as the phosphoric acid method.

Magnesium. Jacquet[13] used a solution of: H_3PO_4 (S.G. 1·71) 375 ml.; Ethyl Alcohol 625 ml., for electropolishing of magnesium and zinc and their alloys. The voltage across the cell is 1–3 volts.

Cadmium. Liger[14] has used a solution of 120 gm./litre KCN + 20 gm./litre $Cd(OH)_2$ with a cell voltage of 4–5 v. and a C.D. of 12–25 amps./dm.^{2} at room temperature. Honeycombe[15] used the Jacquet perchloric-acid –acetic anhydride bath of composition 200 ml. $HClO_4$ (S.G. 1·60), 800 ml. acetic anhydride at a temperature of 35–55° C. with a C.D. of 60–100 amps./dm.^{2} and an external voltage of 25–35 v. Polishing usually takes not less than one minute.

Lead and its Alloys. The use of an electrolytic method enables a polished surface to be obtained free from deformation.

Jacquet[16] used: Glacial acetic acid 650–750 ml.; Perchloric acid (S.G. = 1·61) 250–350 ml.

A C.D. of 20–25 amps./dm.^{2} is necessary and polishing is complete in 5 minutes. Koch and Stanau[17] obtained good results with a bath consisting of: Perchloric acid (S.G. = 1·67) 105 ml.; Water 20 ml.; Acetic anhydride 385 ml. The temperature of the solution is 20–30° C. and the C.D. 10 amps./dm.^{2}

Silver. Gilbertson and Fortner[18] have investigated a bath of the following composition: Silver cyanide 35 gm./litre; KCN 37 gm./litre; K_2CO_3 38 gm./litre.

The critical C.D. varies with the free cyanide content and with 100% free cyanide it was 1 amp./dm.^{2} In a discussion on the above paper Hogaboom referred to the use of: 60 gm. Potassium ferrocyanide; 60 gm. Sodium cyanide in 1 litre of water, which was used for polishing silver filigree work. Very good results are obtained with this solution using a voltage of 6 volts and a C.D. of approximately 0·25 amp./cm.^{2}

Nickel and Cobalt. Nickel and its alloys can be polished in a solution containing 2 vols. methyl alcohol and 1 vol. conc. HNO_3,[19] and Vines[20] states that Inconel and Monel can also be polished with this solution. A C.D. of 80–160 amps./dm.^{2} is used and the polishing time is only of the order of 5–20 secs. The perchloric–acetic acid type of bath also gives good results with these alloys.

Cobalt[18,21] can be electropolished using the phosphoric acid bath.

Steel and Iron. Elmore[22] used a phosphoric acid solution to polish pure iron and single phase iron-silicon alloy and this method is also used by the National Bureau of Standards.[20] A 55% solution of H_3PO_4 is used and the S.G. made up to 1·316 by dissolving iron. A cell voltage of 0·5 v. is usually employed.

Jacquet and Rocquet[23] used the perchloric acetic anhydride bath for the polishing of a number of steels and this method has been examined by a number of other workers.[24,25] The bath composition is: $HClO_4$ (S.G. = 1·61) 185 ml.; Acetic anhydride 765 ml.; Water 50 ml.

The temperature must not be greater than 30° C., with a voltage of 50 v. and a current density of 4–6 amps./dm.^{2} The cathode is an aluminium sheet approximately 20 times the size of the anode. It is better to dissolve 0·5 gms. of aluminium by anodic solution so as to increase the viscosity of the solution, thereby permitting more vigorous agitation of the electrolyte without removing the anodic liquid layer.

Imboden and Sibley[26] investigated a series of solutions based on sulphuric and phosphoric acids, but although satisfactory results were obtained none of these was as good as the Jacquet method. De Sy and Haemers[27] used a solution of the following composition, with the advantage that it is not nearly as dangerous to use as the Jacquet solution: $HClO_4$ (70–72%) 54 ml.; Water 146 ml.; Mixture of alcohol + 3% ether 800 ml. (This solution may also be used to electropolish zinc.)

The main disadvantage of the electrolytic polishing of steel is that non-metallic inclusions and carbide

particles give rise to imperfections in the polished surface due to pits and ridges formed by preferential attack. Apart from this difficulty there is usually very little differential attack on the various constituents in steels.

Zinc and its alloys. Jacquet[13 28] used the phosphoric acid electrolyte for polishing zinc and recommends the same conditions as for magnesium and its alloys. Vernon and Stroud[29] used a 25% solution of KOH, with a c.d. of 16 amps./dm.^{2} and a p.d. of 6 v. The method of Rodda[30] for the electropolishing of brass can be adapted for zinc by the addition of 15 gms./litre of Na_2SO_4. After polishing the specimen is given a chromic acid rinse to prevent stain formation. Parcel[31] gives the following solution for polishing zinc base die-casting alloys: $HClO_4$ (70–72%) 54 ml.; Water 146 ml.; Mixture of alcohol + 3% ether 800 ml.

Tin. A very suitable method is given by Jacquet[32] who uses an electrolyte composed of: Perchloric acid (S.G. = 1·61) 194 ml.; Acetic anhydride 806 ml. The optimum temperature is 15–22° C. with a C.D. between 10 and 15 amps./dm.^{2} and a voltage of 25–40 volts. Five to ten minutes is usually sufficient for polishing. On removal from the cell the specimen should be washed in hot water to prevent staining. This method cannot be used for tin-base alloys.

Tungsten. Dilute solutions of caustic soda were used by Hughes and Coomes[33] for polishing tungsten in the form of large sections or small wires. Peterson, Guarino and Coomes[34] also investigated the polishing of tungsten.

Electropolishing in Industry

The electrolytic method provides a cheap, easily controlled method of producing highly polished surfaces and its applications in industry are many, although the fullest use is not yet made of this excellent method. A polishing procedure destined for industrial use has to be judged by greatly different criteria from one which is used for metallographic purposes. The question of initial cost of the electrolyte, consumption of chemicals, ease of control and handling are all of great importance for the industrial user. In addition, the degree of preliminary mechanical finish necessary to produce a satisfactory final electropolished surface is a factor that has to be taken into consideration. It will be immediately obvious that the perchloric acid solutions used so much for metallographic work have a limited application in industry because of the danger of explosion. Electrolytes based on this substance should never be used in quantities greater than 500 ml.

Stainless steel was the metal that was first polished by the electrolytic method and aluminium is also frequently electropolished. Several other metals are electropolished in industry on a limited scale. The methods of electropolishing used in industry will be briefly commented upon here:—

Methods Applied

Aluminium. There are two main processes for the electropolishing of aluminium, the "Brytal" process used in this country by the British Aluminium Co. Ltd. and the "Alzac" process used by the Aluminium Company of America. The Brytal process consists of a two-stage anodic treatment.[35] The metal is first pickled in a bath of 15% Na_2CO_3 and 5% Na_3PO_4 at a temperature of 74–89° C. After pickling the article is made the anode in the bath and the C.D. adjusted to 50–60 amps./sq. ft. and reduced to 25 amps./sq. ft. when the anodic film has been formed. The voltage is 12–15 v. and the pH of the bath is kept above 10, if necessary, by the addition of ammonia or hydroxylamine. After 10–15 minutes treatment the article is removed and given a cold water rinse. The surface of the aluminium is now brightly polished and covered with a very thin transparent oxide film. The second anodising treatment takes place in a 25% solution of $NaHSO_3$ at 70–120° F. with a C.D. of 6–8 amps./sq. ft. and a voltage of 12 for 20–30 minutes, and is then removed and washed in hot distilled water at 180–185° F. The purpose of this treatment is to strengthen the oxide film and thus preserve the surface finish. The article is finally immersed in a 10% sulphuric acid bath for a few minutes at room temperature, removed and washed in cold and then in hot water.

The Alzac process[7] uses a 2·5% hydrofluoric acid bath. Copper cooling coils serve also as cathode. The temperature of the bath is 30° C., the voltage 15–30 v. and the current density 10–20 amps./sq. ft. After 5–10 minutes treatment, the article is removed and anodised in a 7% sulphuric acid bath at 12 amps./sq. ft. and finally washed in hot water for 10 minutes.

An electrolyte of the following composition is recommended by the Battelle Memorial Institute[36]: Arsenic acid 25% (by weight); Sulphuric acid 15% (by weight); Orthophosphoric acid 35% (by weight); Chromic acid 10% (by weight); Water 15% (by weight).

It should be noted that with the above processes high purity aluminium is necessary to obtain a satisfactory finish; with slightly less pure aluminium a mirror-finish cannot be obtained.

Copper and Brass. A solution containing 900 gms./litre phosphoric acid can be used for the industrial electropolishing of copper and brass and other copper-base alloys.

U.S. Patent 2,330,170 gives the following solution: Water 100 gms.; CrO_3 12·5 gms.; Acetic acid 12·5 gms.; H_2SO_4 10 gms.; $Na_2Cr_2O_7$, 37·5 gms. which is used at 200–400 amps./sq. ft. at 60–75° C. Williams and Rieger[37] recommend a solution of the following composition:—Ammonium acetate 1 part 0·10 M solution; Ammonium hydroxide 3 parts 0·14 M solution; Sodium thiosulphate 3 parts 0·50 M solution; Distilled water 3 parts.

By electropolishing copper and brass can be given a brilliant surface which is equal to that produced by mechanical methods and which possesses an increased corrosion resistance.

Nickel and its alloys. The electropolishing of electrodeposited nickel can be carried out in a solution of 73% by weight sulphuric acid using lead or nickel cathodes, at a temperature of 30° C. and a C.D. of 250 amps./sq. ft. The polishing is complete in ½–3 minutes.

Evans and Lloyd[38] have carried out work on the electropolishing of nickel silver cutlery and find that with nickel silver of from 12–22% Ni best results are obtained by using a bath similar to that used by Uhlig for stainless steel, i.e., a solution containing 37% by volume phosphoric acid, 56% glycerine, 7% water.[39] This bath was used at a temperature of 50–70°C. with a C.D. of 1 amp./sq. in. However, the results are not entirely satisfactory because of the production of a "ripple effect" on the surface of the articles.

Stainless Steel. Zmeskal[40] and Wernick[41] have provided good discussions of the electropolishing of stainless steel showing that a wide range of electrolytes may be used. Phosphoric and sulphuric acids are the basic constituents, to which may be added arsenic, chromic, boric, tartaric, citric, acetic and lactic acids and such organic solvents as alcohol, glycerol and ethylene glycol.

Uhlig's method of using a phosphoric acid—glycerol—water bath is widely used and Evans and Lloyd have recently investigated this method for the polishing of stainless steel cutlery.[38] They find that a solution containing by volume 37% phosphoric acid, 56% glycerine and 7% water gives good results when used at a temperature of 100–120° C. with a C.D. of 5–10 amps./sq. in. Five to ten minutes in this bath gave an excellent finish on stainless steel spoons that had previously been "barrelled."

Wernick[41] in his discussion pays some attention to the effect of alloying elements on the polishing of stainless steel. He finds that a straight 18–8 steel gives the best results and the effect of alloying is shown in Table II.

TABLE II.
EFFECT OF ALLOYING CONSTITUENTS ON 18-8 STAINLESS STEEL (WERNICK).

No.	Additional Constituent	Degree of Polish
1 ..	None	Good polish
2 ..	Upwards of 0·5% copper	Good polish, but inferior to 1
3 ..	Copper 0·5%; Tungsten 0·5–1%; Titanium 1%	Fair polish, some etching
4 ..	Copper 0·5%; Tungsten 1·0% ..	Mild polishing action
5 ..	Molybdenum 3–4%	As No. 4, but additional bloom

Plain Carbon Steels. The electropolishing of plain carbon steels is very difficult on an industrial scale. The perchloric acid–acetic anhydride solution of Jacquet and Rocquet[23] is quite successful in the laboratory but its use on a large scale is obviously difficult because of the danger in handling. It may, however, find use in the polishing of small tools. Solutions based on sulphuric acid and phosphoric acid have been used to polish ordinary steels and these would seem to be better suited to industrial conditions. However, the presence of slag and carbide particles in plain carbon steels makes it seem improbable that any high degree of polish, such as is given to stainless steels, can be obtained.

Multipurpose Electrolytes

The Battelle Memorial Institute[42] has developed a series of electrolytes based on arsenic acid which may be used for polishing several metals. The baths of the following compositions are claimed to be able to polish stainless steel, rustless iron, nickel and nickel alloys (Monel), copper, brass and cupro-nickel.

TABLE III.—MULTIPURPOSE ELECTROLYTE.

Constituents	Percentage by weight		
	1	2	3
Sulphuric Acid	36%	25%	10%
Arsenic Acid	47%	69%	77%
Water	17%	6%	13%

Temperature = 60° C.
C.D. = 50–100 amps./sq. ft.

Conclusions

It will readily be seen from the above review that the applications of electropolishing are wide and numerous and the electrolytic method provides a cheap and easily controlled means of producing a high polish on the surface of many metals. Further investigations of the critical conditions of electrolytic polishing will, undoubtedly, increase the scope and variety of this method and make possible a wider use in industry. Increasing interest should be taken in electropolishing and much more use made of this technique which in the laboratory alone can result in a saving of many man-hours of labour both in the mechanical polishing of specimens and in the elucidation of structures that have been deformed and distorted by the usual means of preparation.

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Copper Development Association

SPEAKING at the recent annual general meeting of the above Association, Lt. Col. the Hon. R. M. Preston, D.S.O., Chairman of the Council, reported another year of steady progress. He considered that at a time when industrial efficiency and knowledge must be brought to their highest pitch, associations such as this render an important national service. He emphasised the provision of a highly specialised and expert service of technical advice, instruction and information, to all who desire to avail themselves of it. Moreover, in doing so the object is not to concentrate only on an expansion of the use of copper, but rather at all times to improve the efficiency of its application, which is a matter not only of great national importance, but also in the best interests of the Association's members.

Special reference was made to the immediate importance of the Association's work in promoting the use of copper compounds in agriculture. The effectiveness of copper sulphate, for instance, properly applied, in preventing potato blight is fully established and is urged at all times by the Ministry of Agriculture. The amount of copper required to provide spray for all potatoes grown in this country in areas susceptible to blight is probably not more than 1,200 or 1,300 tons, which is a small price to pay for insurance against short commons.

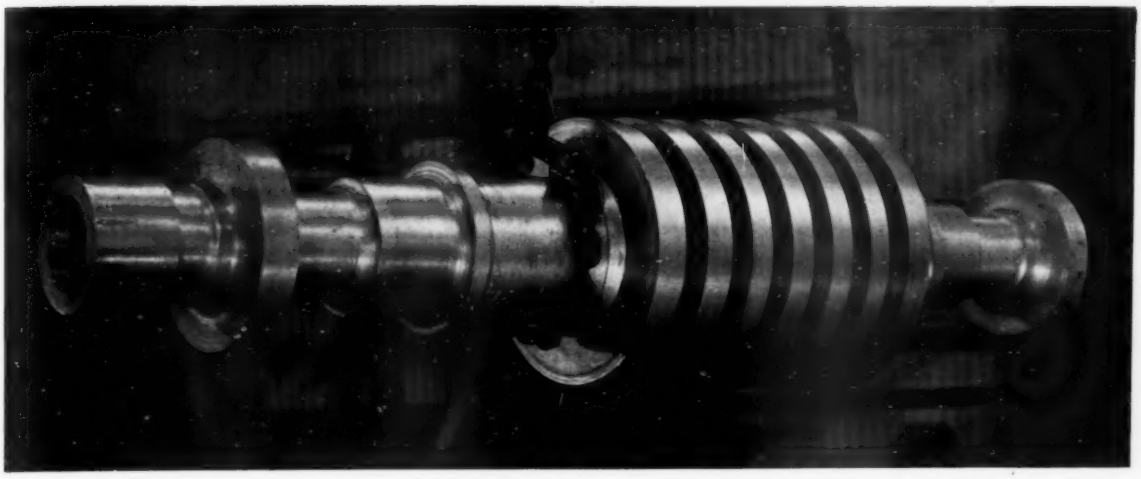

Fig. 1.—Gas turbine shaft forging in nickel-chromium-manganese-cobalt-columbium steel.

Developments in Alloy and Special Steels

By Dr. C. Sykes, F.R.S.

Director, The Brown-Firth Research Laboratories

In the metallurgical field efforts are constantly being made to provide engineers with new or improved alloys capable of giving increased service under specific conditions. In recent years, much attention has been directed to achievements with the gas turbine, made possible by the development of new heat- and creep-resisting alloys, but this should be regarded as a typical example since steady advances are being made in the development and production of alloy steels for a multiplicity of purposes involving severe service conditions. Many factors, however, must be studied with a view to determining their influence and to effecting some control of variables inseparable from steel production and use. The importance of some of these factors is emphasised in this review.

PERHAPS the most important development in special steels during the year has been the extension and application of heat-resisting and creep-resisting steels to gas turbine applications.

Apart from investigations designed to develop new materials, results have been reported of a number of major investigations concerned with the evaluation of factors affecting the quality of existing steel products. Amongst these, reference may be made to the study of the overheating of steel and the interpretation of the hardenability test, both of which formed the subject of a symposium organised by the Iron and Steel Institute. There has also been much progress in the determination of the effects of occluded hydrogen on the properties and behaviour of steel and its association with the formation of hair-line cracks. The treatment of steel with lead, sulphur or other free-machining additions has continued to receive attention and the whole subject of machinability has formed the subject of a Symposium held by the Institution of Mechanical Engineers.[1]

Heat-resisting Steels

The progress made during the war in the development of material for the discs and blades for the jet engine was spectacular. The main requirements of alloys for these high temperature applications are :—

(1) Good creep strength at the working temperature, say about 750° C.
(2) Resistance to scaling.
(3) Structural stability over long periods of exposure at the working temperature.

Data on a variety of alloy compositions, developed and investigated during the war has now been published both in America and in this country.[2, 3, 4, 5] American literature is rich in the variety of alloys examined, although in many cases, as one might expect, the data on properties at elevated temperatures are rather sketchy. A number of the more important compositions used for blading and for discs in this country and America is given in Table I ; they may be classified roughly as follows :—

(*a*) Iron base—austenitic steels.
(*b*) Nickel base—nichrome type.
(*c*) Cobalt base.

All the materials contain substantial proportions of chromium to provide adequate scaling resistance. In general, the desirable creep properties are obtained by submitting the materials to a solution treatment at a high temperature—often near to the solidus temperature followed by a precipitation treatment in the region of the desired working temperature.

Of the American alloys 16/25/6 as a disc material and S816, Hastelloy B, K42B and Vitallium as blading materials have had wide applications in the American

Fig. 2.—Gas turbine blades produced by drop-stamping.

Fig. 3.—Gas turbine blade produced by the "lost wax" process.

TABLE I.—COMPOSITION OF CREEP RESISTING STEELS USED FOR GAS TURBINES—BLADES AND DISCS.

	C	Si	Mn	Ni	Cr	Mo	W	Cu	Co	Ti	Cb	Al	N
Nimonic 80	·04	·5	·5	75	20	—	—	—	—	2·5	—	·5	—
G.18B ..	·4	1·0	·8	13	13	2	2·5	—	10	—	3	—	—
R. ex 78 ..	·1	·5	·5	18	14	3·5	—	3·5	—	·75	—	—	—
R. ex 337A	·2	·5	·5	18	14	3·5	—	3·5	7	·75	—	—	—
*16/25/6 ..	·05	·8	1·5	25	16·5	6·25	—	—	—	—	—	—	·1
*Hastelloy B	·05	·25	·6	65	—	29	—	—	—	—	—	—	—
*K42B ..	·05	·4	·7	42	18	—	—	—	22	2·2	—	—	—
*Vitallium ..	·3	·25	·3	2	27	5	—	—	Rest	—	—	—	—
*X40	·5	·7	·6	9·5	25	7·25	—	—	55	—	—	—	—
*8590	·4	·6	·8	20	20	4	4	—	20	—	4	—	—
*8816	·4	·6	·6	29	20	4	4	—	44	—	—	—	—
*422–19 ..	·45	·25	·3	27	16	6	—	—	50	—	—	—	—
*N155	1·–4	·5	1·0	20	20	3	2	—	20	—	1	—	·14
*19/9 DL ..	·3	·55	1·0	9	19	1·25	1·25	—	—	·3	·4	—	—

* American Alloys

jet engine. In this country Nimonic 80 as blading material and G18B as a disc material, have been used extensively.

The success of the jet engine has given a great fillip to the development and commercial utilisation of the gas turbine. Whilst both devices are very similar in principle, certain practical differences arise which involve important metallurgical considerations. Firstly, the "design" life of a gas turbine is of the order of 100,000 hours, whereas the "design" life of a jet engine is about 300 hours. Creep testing to cover the latter is a relatively simple matter and the appropriate data are now available, but long-term data, i.e., 10,000 hours or greater is much more difficult to accumulate and at present are extremely scarce. The size of forgings, etc. for gas turbine rotors is a good deal larger than that of the discs in aero-engines and since the heat-resisting alloys by virtue of their superior creep properties are generally difficult to forge, the production of forgings suitable for gas turbine rotors has presented certain problems to the forgemaster. The gas turbine has to compete with existing equipment such as the steam turbine and the diesel engine, consequently not only must its efficiency be much higher than that of the jet engine, but the overall cost and reliability must be comparable with that of existing installations. This means, of course, that the steelmaker must be very critical of the expensive alloying additions used in the steels developed during the war.

Much progress has been made on these problems during the past year, and numerous large forgings have been produced by the forgemasters. Certain turbine designers favour a single piece rotor, others use a built-up construction consisting of end forgings and discs. Fig. 1 shows a typical forging in one of the special heat-resisting steels.

On the blading side, apart from the question of mechanical properties, much attention has been paid to methods of production which minimise the amount of machining necessary. As might be anticipated, many of the materials under consideration are difficult to machine and special shapes demanded by the blade designer do not simplify the machining problem. At the present time, blades are being produced by three main processes—direct machining from bar, by drop stamping which produces a blade within ·030 in. or less of the finished dimensions and by the "lost wax" casting method. This last method, which is extensively used in America, is claimed to produce a blade to the finished size and contour which requires no machining. Provided these claims can be achieved, this process is very attractive, since not only does it eliminate machining costs, but it enables the steelmaker to develop alloys without the restriction that they must be sufficiently ductile to forge. Much development work on this method of manufacture is now in progress, but so far, the method has not been used for the routine production of moving blades in this country. Figs. 2 and 3 show typical examples of drop-forged blades and blades made by the "lost wax" process.

The Overheating of Steel

During the war, aircraft engine builders were troubled with overheating in drop-stamped parts made from alloy steels and since that time the problem has been examined in detail by Mr. Preece[8] of Leeds University, working in collaboration with the Alloy Steels Committee and by a number of other investigators.[7, 8, 9, 10] Overheated steel when fractured in the hardened and tempered condition shows dull facets and, depending on the degree of overheating, the ductility—particularly the reduction in area, and the fatigue limit are reduced to a greater or less extent.

As a result of the various researches certain practical aspects of this problem have been clearly defined. The minimum overheating temperature depends on the "purity" of the steel and consequently is affected by the steel-making processes used. Thus the minimum overheating temperature is substantially lower in general for electric steel than for Siemen's open-hearth steel. In all cases, however, the minimum overheating temperature is above that necessary to carry out ordinary forging and drop-stamping operations, consequently, if reasonable control is maintained over the temperature in forge-reheating furnaces overheating will not occur.

One interesting fact arising from Preece's work is that the overheated structure occurs when the material is cooled at an intermediate rate from the high temperature

—at faster or slower rates the overheated structure may be either eliminated or suppressed. This together with the fact that the overheating temperature is very materially raised in the presence of high oxygen, high sulphur and high inclusion contents (see Fig. 4) suggests that overheating is concerned in some way with a precipitation process, but no hypothesis has yet been advanced which is completely acceptable from the theoretical point of view.

It has been shown that the overheating temperature is independent of the atmosphere in which the material is heated—thus steel may be overheated in high vacuo just as readily as in an industrial furnace. This observation emphasises the important difference which exists between overheating and burning and the necessity to avoid confustion by the indiscriminate use of the two terms.

Hardenability

This is another subject which became of major importance during the war when the maximum economy in alloying elements was necessary and which now, as a result of much extensive work, has yielded results of considerable value both to the steelmaker and the consumer. The special committee set up by the T.A.C. under the Chairmanship of Mr. D. A. Oliver recently presented its report[11] and this was subsequently discussed at a meeting of the Iron and Steel Institute. This report is a most comprehensive and valuable document.

It is only possible in this article to deal with some of the major conclusions of the report. Firstly, it has been established that the Jominy end quench test as a test gives results which are readily reproducible and one not affected by normal variations in testing conditions. On the other hand the hardenability of different casts of steel of the same analysis may vary substantially and similarly significant variations in hardenability may occur in samples taken from different parts of the same ingot—thus it is clear that the hardenability of a steel cannot as yet be precisely calculated from a knowledge of the analysis and grain size of the steel.

The Committee found that the hardness traverse curves of oil quenched bars cannot be derived consistently with adequate accuracy from a single end quench curve. As regards the relationships between hardenability and mechanical properties, it was found that whilst the mechanical properties of steel that has been quenched and then tempered in the range 500°–600° C. depend on the hardness developed on quenching there are serious difficulties in the way of interpreting end quench curves in terms of the ability of steels to attain a required combination of properties such as ultimate strength and izod impact.

The izod impact value and yield ratio of steels quenched and subsequently tempered at 500°–600° C. to give the same maximum stress value tend to decrease as the hardness in the quenched condition, i.e., the hardenability decreases, whilst the elongation and reduction in area are not greatly affected. The combination of mechanical properties usually demanded may often be obtained from steel which is incompletely hardened during quenching, but the minimum value of the as-quenched hardness required to develop the combination must be determined from direct tests.

As regards alloy conservation, the American conclusion has been confirmed that an addition made up of small additions of a number of elements such as manganese, chromium, molybdenum, gives a greater increase in hardenability than the same total addition consisting entirely of one element and much data on the relative efficiency of the different elements both singly and in combination are given in the report. Here again it appears that no simple formula exists which gives an accurate correlation between hardenability and composition.

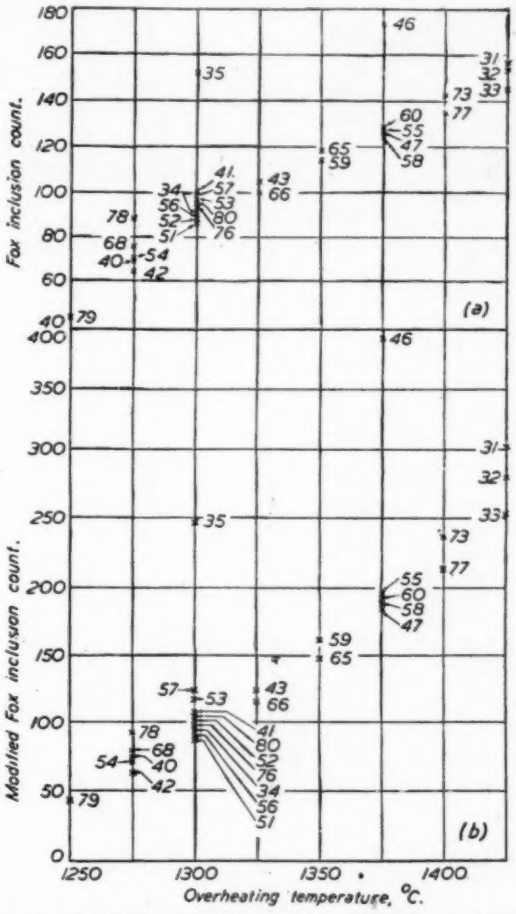

Fig. 4.—Incipient overheating temperature plotted against (a) the Fox inclusion count, and (b) the modified Fox inclusion count. (Numbers refer to samples.)

Thus, whilst the Hardenability Sub-committee have not confirmed the many optimisitic claims made relating chemical composition to hardenability on the one hand, and hardenability to mechanical properties in the heat-treated condition on the other, they have shown that the Jominy end quench test is not only a very reproducible test, but also that it is an excellent laboratory test for placing steels in order of merit as regards hardenability and that it gives a very useful first approximation to the merits of a given steel. As to whether a steel with a particular hardenability will give satisfactory mechanical properties in a particular section must be decided by trial—actually, of course, the method of trial—apart from giving the final answer —is also, in many cases, far simpler than the involved mathematical processes which have been developed in an endeavour to predict the mechanical properties of a steel in any given section from the Jominy curve.

Fig. 5.—Forged roll in free cutting stainless steel.

The variations in harderability revealed by the Jominy test in material purporting to have the same chemical analysis are substantial and it is clear that there are aspects of the steelmaking procedure which will need more careful control if these variations are to be reduced. Here again, the Jominy end quench test will provide an excellent control; however, until these variations are understood and eliminated, it is futile to expect any precise correlation between chemical analysis and hardenability.

Hydrogen and Hair-line Cracks

This subject has been under active discussion since the 1914–18 war when the phenomenon of hair-line cracks was recognised in alloy steels. Andrew and his collaborators have studied the subject intensively and have shown that steel impregnated with hydrogen is more susceptible to cracking and has lower ductility than steel free from hydrogen. Recently, a further paper by Andrew and his co-workers[12] and a paper by Sykes, Burton and Gegg[13] dealing with the incidence of hydrogen during manufacture have been discussed at the Iron and Steel Institute. In this latter paper, the mechanical properties of various products—forgings, billets, bars, were determined together with the hydrogen content naturally arising in the material as manufactured.

These results show quite conclusively that whether the hydrogen content arises normally or is intentionally introduced, an embrittling effect occurs. The magnitude of the embrittling effect, depends, amongst other factors, on the tensile strength of the steel, thus at 4 ccs./100 grams marked reduction in elongation and reduction of area is observed at all tonnages, but with 2ccs./100 grams the embrittlement, which is appreciable in the 100 ton condition, is only slight in the 45 ton condition.

Whilst the embrittling effect of hydrogen can now be considered as established it is now considered doubtful whether any precise relation exists between hydrogen content and the presence or otherwise of hair-line cracks. Thus Andrew expresses the view that the hydrogen content is not the only controlling factor in the formation of hair-line cracks and Sykes showed that using steel from the same cast, billets containing 10 ccs. hydrogen/100 grams could be crack-free, whereas other billets containing 3 ccs. hydrogen/100 grams and having a somewhat different heat treatment were cracked.

Whilst this is a highly controversial subject most metallurgists familiar with the question will probably agree that if hydrogen could be eliminated from steel the incidence of hair-line cracks would be reduced. From the data reported in the paper mentioned it appears that the hydrogen content of acid open hearth steel is about 4 ccs./100 grams and of basic electric steel 6–8 ccs./100 grams in the ladle. Neglecting any considerations regarding segregation during freezing to reduce these concentrations to say 1 cc./100 grams, requires heat treatments of the following magnitude at say 650° C. :—

1 in. bar	1 hour
10 in. bar	100 hours
20 in. bar	400 hours
40 in. bar	1,600 hours

These facts regarding hydrogen content and diffusion are in general agreement with experience on hair line crack occurrence, thus less trouble is experienced with acid open hearth steel than electric arc steel and the prevention of hair cracks only becomes a difficult problem when the ruling section is very large, say 30 inches diameter and over, and is thus primarily the concern of the producer of large alloy steel forgings.

There is reliable evidence which indicates that in many cases the cracks form at room temperature usually after an incubation period, but why they form is still a matter for speculation. Various theories have been advanced from time to time—the breakdown of residual austenite producing local stresses—the breakdown of a hydrogen-rich compound—the production of very large pressures by molecular hydrogen. None of these theories gives a satisfactory explanation of all the known facts, so that whilst it may be concluded that our knowledge of the occurrence and effects of hydrogen in steel has been materially advanced by these researches, it must also be said that the allied problem of hair-line crack formation still remains a subject for speculation.

Machinability

Much interest is taken both in the subject of machinability and the properties and development of steels with free-machining properties. The plain carbon and low tensile alloy steels have been treated with sulphur additions and more recently with lead additions, and from the point of view of machinability marked improvements

have been achieved. With sulphur additions, a noticeable deterioration in mechanical- and fatigue-properties takes place in the transverse direction.

The application of sulphur additions to 18/8 austenitic steels and to the 14% chromium martensitic steels leads to similar improvements in machinability, particularly for operations such as drilling and sawing. This improvement is obtained without any deterioration in corrosion resistance and for the many applications where the transverse properties required are not critical these free-machining steels are replacing the existing steels. This is particularly the case, for example, in austenitic steel castings where the free-machining properties lead to great savings in machining time. Fig. 5 is a photograph of a forged roll for a paper manufacturing plant produced in a free machining martensitic steel (14% Cr type). When installed, this drum will contain some 100,000 radial holes. The following data indicate the improvement in drilling achieved by the sulphur addition :—

	Feed per minute	Number of holes drilled
Plain Chromium Steel (14% Cr)	8 in.	2
Similar with Sulphur addition	8 in.	280 drill still cutting

(Drill used ¼ in. diameter High Speed Steel, 1,500 revs./min., ⅜ in. depth of hole)

The sulphur additions introduce certain difficulties during the hot-working operations; the sensitivity of the ingots etc. to cracking during rolling is increased. Further, in the case of the high tonnage highly alloyed ferritic steels many designers are unable to accept improved machinability at the expense of a deterioration in tranverse properties. As a result of these considerations the active production of leaded alloy steels is now in hand. Initial investigations[14] indicate that, at any rate, up to 65 tons tensile, practically no deterioration in mechanical properties accompanied the improved machinability. If this is confirmed over the wide range of alloy steels used in the high tensile condition, then the existing demand for leaded alloy steels is likely to increase materially.

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Development of Wimet Slitting Discs

THE development of Wimet slitting discs for shearing high-carbon steel razor-blade strip provides an interesting example of the development of a carbide-cutting application. At the back of this development are the outstanding results obtained with a set of Wimet discs which have sheared over 37 times more strip between regrinds than was possible with the cast steel cutting discs previously used.

The performance of this set of discs is reported by Samuel Fox and Co., Ltd., Stocksbridge, Sheffield, where the discs are used for shearing off the scrap edges of razor-blade strip 0·007 in. thick by 6½ in. wide, reducing the finished width to 5¾ in. The normal life between regrinds of the cast-steel discs previously used was 8 coils (3 tons or 14,000 ft.) of strip, whereas on the first run the Wimet discs sheared 303 coils (121 tons or 561,000 ft.) of strip and were then reground only because one of the discs was chipped.

The machine employed is of the pull-through type in which the two cutter spindles are not driven. The cutter is formed of four discs, each 6½ in. in diameter and ½ in. wide, provided with Wimet cutting edges and keyed to the cutter spindles with spacing collars between. The speed of operation varies between 470 and 650 ft. per minute depending on the build-up of the coil. Following this successful application, a cutter has now been designed with eight Wimet discs for shearing similar high-carbon steel razor-blade strip into six single blade widths. Three discs on each spindle are provided with double Wimet cutting edges, and their width corresponds to the required strip width. The fourth disc on each spindle provides the single, outside cutting edge.

Cambridge High Vacuum Symposium

LEADING scientists from the United States and abroad attended a recent meeting, sponsored by National Research Corporation of Cambridge in co-operation with the Division of Industrial and Engineering Chemistry of the American Chemical Society, devoted to discussions of the latest techniques and developments in the rapidly growing field of high vacuum. Under the general chairmanship of Richard S. Morse, President, National Research Corporation, assisted by Dr. John R. Bowman of the Mellon Institute of Industrial Research, the various sections of the meeting stressed the different aspects of high vacuum.

Dr. Saul Dushman, Assistant Director, General Electric Research Laboratories, led the group discussing the early history of high vacuum and basic research which led to its present-day development. Dr. Bowman's session covered the field of high vacuum distillation which has led to the production in commercial quantities of vitamins, plasticisers and many other substances which could not be fractionated previous to the development of high vacuum. Problems in connection with large-scale commercial installation of high vacuum equipment were discussed by outstanding engineers, under the leadership of Dr. John C. Hecker, Works Manager, Distillation Products, Inc., and formerly production manager of one of the atomic energy production plants at Oak Ridge, Tennessee. While the many new developments in the field of high vacuum metallurgy were discussed by scientists led by Dr. John Chipman Head, Metallurgical Department, Massachusetts Institute of Technology. These discussions covered recent developments in the commercial production of magnesium, gas-free copper and improvements in sintering.

Copper and Copper Alloys

A Survey of Technical Information During 1947

By E. Voce, Ph.D., M.Sc., F.I.M.

Steady and persistent progress has been made in the production and application of copper and copper alloys and in grappling with the problems underlying their behaviour. In this survey it will be seen that developments cover a wide field, including casting and fabricating operations, many aspects concerning properties, corrosion and protection, activity in the powder metallurgy field, joining technique, metal finishing, and physical metallurgy and testing; developments that represent a body of solid achievement.

DURING the year a large number of technical publications bearing either directly or indirectly on copper and its alloys have appeared and, while none has been revolutionary in character, in the aggregate they represent a body of solid achievement.

No less than three important symposia, on electrodeposition, powder metallurgy and internal stresses respectively, have been held in this country, and others have taken place elsewhere.

The science of conventional metallurgy, as distinct from that based on atomic physics, would at first sight appear to be entering a relatively quiescent period, following the establishment of most of the ordinary properties of most of the ordinary materials. Closer examination shows, however, that this apparent complacency is an illusion, and that investigators everywhere are grappling with the intricate problems underlying the behaviour of metals, such for instance as recrystallisation and grain growth, the fundamentals of oxidation both superficial and internal, the mechanism of fracture and the inter-relationship of stress and strain in the plastic region, as well as fatigue, corrosion fatigue, cavitation and intercrystalline cracking. Some evidence of the impingement of this type of research on copper and its alloys during the year is indicated in the pages which follow, as a background to a review of the principal technical papers which have been published. Some of the newer and less orthodox ideas and suggestions which have been advanced are mentioned in the hope that practical men will find them stimulating.

The Production of Copper

World Consumption and Reserves.—Consumption of copper in Great Britain continues to increase. For the first three-quarters of 1947, excluding the abnormal month of February, it averaged 30,200 long tons a month compared with 27,100 tons a month for 1946 and 24,100 tons for 1945. Before the war, in 1938, it was no more than 21,500 tons a month. The American demand has been extremely heavy and could not be satisfied by domestic production, with the inevitable result that competition for supplies outside the United States was severe. American interest in foreign ore reserves is reflected in a comprehensive review under the authorship of Shea[1] who estimated the potential output of new copper by the British Commonwealth for 1947 to be 700,000 short tons. Compared with actual production, Shea's figure may be too high by some 150,000 short tons, but it is believed that, had all the mines been able to work at their maximum capacity, an output approximating to that which he forecast could have been achieved. Other statistics in the paper make it apparent that the known reserves of copper ore are limited, and much activity in prospecting for new deposits is in progress, especially in America. Unexplored reserves in Rhodesia are reported to be very extensive, and may be supplemented by deposits in South West Africa, while quantities of sulphide ore have been located at Fungurme by the Belgian Union Miniere du Haut-Katanga. Extensive low grade ore-bodies at San Manuel in Arizona and in Butte, Montana, are about to be developed, while a new smelting plant is to be installed at Paipote in Chile.

Individual Mining Enterprises.—During the year, the mine at Nchanga has been coming into full-scale production and a paper by Talbot[2] describes the methods adopted for treatment of the ores, which contain both sulphide and oxide minerals. Flotation of sulphides presents no special problem, but considerable effort was expended to good effect in developing means for the treatment of the oxide constituents of the ores. From the pilot plant, which was first installed, both concentrates were delivered together to the smelter, but it was found that an uneconomical proportion of fluxes had to be used in the matting furnace in order to remove gangue from the oxide concentrates. It is proposed, therefore, to pass only the sulphide concentrates to the smelter and to leech the oxide concentrates, precipitating the dissolved copper electrolytically.

Several descriptions of individual mining and smelting enterprises have appeared, particularly of the Morenci Mine of Phelps Dodge[3], Ookiep[4] and Outokumpu in Finland,[5] while Canadian,[6] Californian,[7] Belgian[8] and Swedish[9] production has been reviewed. Most cases were characterised by great activity and expansion, Ookiep[10] having acquired the assets of the German Otavi Minen Und Eisenbahn Gesellschaft while at Bagdad, Arizona, open pit mining has been adopted with much reduced costs.[11]

Publications summarising the production of copper are somewhat rare, and a brief account[12] of the principal ores and the operations involved in smelting them to matte, converting to blister copper, refining and the production of wire is therefore welcome.

In the Foundry

Inspection, Testing and Control.—The new "Code of Procedure in Inspection of Copper-Base Alloy Sand Castings" has now been formally issued by the British Standards Institution as B.S. No. 1367.[13] Special

SHEAR STRESS OF COLD-ROLLED COPPER AND BRASS

Material	Final rolling reduction %	Diamond pyramid hardness No.	Shear stress (square punch) tons/sq. in.	Tensile strength (transverse) tons/sq. in.	Elongation (transverse) % on 4 area
H.C. Copper	0	48	9·9	13·6	50·0
	9·0	77	11·0	15·5	35·8
	18·7	90	11·8	18·5	11·5
	29·0	100	12·3	20·5	4·0
	39·0	105	12·6	22·3	3·0
	48·1	109	13·0	24·6	3·0
	59·2	115	13·5	25·9	2·5
	72·7	117	14·0	26·9	2·5
	75·5	118	14·1	27·6	2·0
	89·4	121	14·5	27·6	2·0
70 : 30 Brass	0	64	15·9	20·8	66·0
	9·16	97	16·8	22·6	50·3
	20·8	128	18·6	26·2	33·0
	28·4	145	19·8	29·8	20·5
	36·4	156	21·1	33·3	11·5
	50·5	172	23·1	39·1	9·0
	59·7	181	24·1	42·3	8·0
	70·0	190	25·1	45·9	6·5
	75·0	194	25·6	47·7	5·5
	89·0	207	26·5	50·7	4·5

attention should be given to the form of tensile bar which it prescribes, and to the advantages of using separately cast test bars in preference to those attached to the casting.

Another valuable contribution to the systematisation of foundry knowledge is the "Atlas of Defects in Castings" published by the Institute of British Foundrymen.[14] It comprises a collection of photographs of defects which may occur in castings. In each case the cause is explained and remedies are suggested. Though most of the examples are ferrous in character, many apply equally well to copper alloy castings.

A sound practical paper[15] on modern methods of foundry control has been contributed by Baker, who describes the various operations involved in the production of a casting and indicates their priorities in the scheme of control. The paper, which is written in very general terms, will amply repay study by all founders who have the improvement of their products at heart.

New Developments.—From America, suggestions [16, 17] come for the introduction of perforated discs of metal or of graphite between the casting and the gate or risers. These serve the double purpose of filtering the stream of metal from dross and providing a plane of weakness at which the riser can be removed by a single blow from a hand sledge, with obvious saving of fettling costs compared with sawing. It is claimed that the advantages are more apparent in non-ferrous than in ferrous work ; perforated metal screens function best in brass risers not in excess of 5 in. diameter, while carbon discs are equally effective in brass and bronze risers of all sizes.

For repetition foundry work the use of plastic patterns merits consideration.[18 19] Even for a large output it might seldom be economical to prepare dies and to form patterns moulded from thermo-setting plastics in the normal way, but plastics which can themselves be cast in plaster moulds prepared from prototype wooden patterns are now readily available. They are generally in the form of a viscous resin which, soon after the addition of a suitable acid hardener, sets to a rigid material which will take a good polish. Among the advantages claimed are cheapness and ease of reproduction compared with duplicated wooden patterns, lightness and smoothness of surface compared with cast metal patterns, permanence of dimensions in spite of atmospheric changes, and ease of patching if damaged. In addition to the acid setting type of resin, others are available which set on the application of gentle heat.

Semi-Continuous Casting.—Much use has been made in Germany of the semi-continuous casting process for the production of wrought light alloys[20] and there seems little reason why similar methods should not be applied to brass, nickel silver and similar copper alloys for strip. The plant is less complicated than that required for fully continuous casting, and occasional stoppages for repairs would cause much less serious loss of production. Billets 10 ft. in length are obtainable.

Centrifugal Casting.—Two contributions to knowledge of the centrifugal casting of copper alloys have recently been made, each for a specialised purpose. Lee and Northcott[21] closely investigated the centrifugal casting of wheels in sand moulds, and found that alloys of narrow freezing range such as aluminium bronze and high tensile brass, were less improved by centrifugal casting than were those of wider freezing range like the tin bronzes and gunmetals. The greatest improvement in properties was obtained with phosphor-bronze, and annealing to absorb the eutectoid into solid solution caused a greater increase in mechanical properties in centrifugal than in static castings. The process caused no more than slight segregation of lead in leaded gunmetals.

Crow[22] describes tests on an industrial scale of the centrifugal casting of 63 : 37 brass "ingots" for cold rolling. The machine was essentially similar to that used in the well-known Soro process, except that a cylindrical shell rather than a ring is produced. It is claimed that strip more consistently free from defects is obtained by the spun-cast method ; so much so, in fact, that certain customers are willing to pay an increased price for it.

The Casting of Bronzes and Nickel Silvers.—So much has been written in recent years concerning the casting of bronzes and gunmetals that it seems unnecessary to do more than call attention to several fresh publications on the subject.[23-29] However, a recent paper by Baker[30] has presented a brief, but comprehensive, summary of the position and it seems worth while, even at the risk of repetition, to quote some of his findings.

It is recognised that one of the most prevalent causes of porosity is the liberation of hydrogen from the melt during solidification. Hydrogen can be absorbed by molten bronze from the furnace atmosphere if this is of a reducing nature, or if both the water content of the atmosphere and the phosphorus content of the bronze are high. In addition, hydrogen can be picked up after pouring, by the interaction of phosphorus with moisture in the mould.

Several methods of removing gas are now well established ; of these the most convenient appears to be the introduction of a small quantity of manganese ore into the bottom of the pot, where it sticks and evolves oxygen or carbon monoxide by reaction with the graphite of the crucible. This relatively inert gas, rising through the melt, carries with it the unwanted hydrogen. Alternatively, marble chips may be plunged beneath the surface of the molten alloy where they evolve carbon dioxide which has an equally scavenging action. Baker also describes the method advocated by Pell-Walpole in which an oxidising flux consisting of copper oxide, borax and silica sand is thrown upon the surface of the melt, and attributes the efficacy of this

process more to preventive action than to a strictly de-gassing treatment.

For simple forms of casting the phosphorus content of the alloy and the pouring temperature should be kept to the lowest practicable level, but where high phosphorus contents are required it is desirable to use a coating of aluminium paint on the mould surfaces in order to minimise the possible introduction of gas from moisture in the sand. For more intricate castings of variable section where complete feeding is impracticable, the phosphorus content and the pouring temperature may be raised to levels which cause a moderate amount of gas absorption from the mould, and in this way the porosity which is inevitably present in the casting will be distributed as uniformly as possible, with considerable improvement in what would otherwise be the most porous parts.

While it is impossible to lay down hard and fast rules applicable to all castings, it is recommended that a pouring temperature of from 1,080–1,180° C. should be used for phosphorus contents between 0·01 and 0·10% while for 0·25% phosphorus the pouring temperature may be from 1,050–1,150° C. and for 0·5% phosphorus from 1,020–1,120° C.

As much less has been written on the casting of nickel silvers and similar alloys a recent paper on the subject[31] should be mentioned. Useful information is given on such aspects as melting, alloying, fluxes and deoxidising agents, the effect of impurities, pouring temperature, moulding sand and gating, with tables to show the chemical composition and properties of a number of typical alloys. The article forms part of a comprehensive review of non-ferrous foundry practice.

Fabrication Processes

Comparison of Forging with Die Casting.—In cases where several different methods of making a given product are available, a considered comparison of their relative merits is of value. A particularly useful article covering every aspect of brass press-forging versus die casting has been contributed by Chase,[32] who points out that to make a selection between these two methods it is necessary to consider some eighteen different factors independently, and thereby to arrive at a compromise best suited to the purpose in hand. In one case, for instance, dimensional tolerances may be of more importance than production rates and labour costs, and the paper gives a detailed guide as to how such factors and many others like them, can be assessed.

The same author[33] has indicated the advantages of using rod extruded to a sectional shape which will permit the metal to fill the forging die with the minimum deformation. In this way it may be possible to reduce the number of forging operations compared with those required to produce the same product from ordinary round bar. He points out that to extrude a shaped section is scarcely more expensive than to extrude a round.

Rolling.—The Iron and Steel Research Association is at present engaged in an extensive series of experiments on the cold rolling of steel and high conductivity copper, and a paper, under the authorship of Ford[34] has already appeared on the subject. This is concerned mainly with the effect of speed of rolling, and confirms previous researches in that with pass reductions up to 60% the rolling pressure required for the first pass is substantially independent of the speed. In subsequent passes, however, after work hardening and when the strip is thin, rolling pressure is markedly dependent on speed and is highest at the lower speeds. Cook and Larke[35] have described how rolling loads may be calculated.

Deep Drawing Operations.—Baldwin and Howald[36] have reported a theoretical and experimental investigation of the tendency of a circular blank to fold when drawn into a cup. Tests on copper and brass were included among other materials, under a wide range of conditions. It was found possible to predict the tendency of a blank to fold if the true stress-strain diagram of the metal is known.

A short article in the *Machinist*[37] gives an account of the shaping of steel by the Guerin process which has been widely used for the forming of aluminium sheet on presses equipped with rubber pads. It is clear that if steel can be so handled, it is possible to use the same method for brass and similar copper alloys.

An interesting development in deep drawing is the use of a thin film of plastic material on the surface of the sheet to be drawn.[38] This protects the material from direct contact with the dies and preserves a high grade finish. It is particularly suitable for stainless steel where damage to the surface involves considerable labour in repolishing, but can also be applied to brass and copper alloys where high surface quality is a prime necessity. The coating can subsequently be stripped from the metal surface with ease.

Electroforming.—Interest in electroforming has been stimulated by articles from Ollard[39] and from Clauser,[40] who illustrate the adaptation of the process to modern engineering requirements. The high degree of precision obtainable is apparent from the accuracy with which dies for the production of gramophone discs are regularly made: but it is less well known that, for this reason, electroforming is finding increasing applications in instrument making and similar industries. Its use, however, is by no means confined to cases where high precision is required: it is already contributing to the expansion of the copper plumbing industry by providing a ready means of producing complicated branched unions of all sizes and shapes.

Properties of Copper and Copper Alloys

Cold Working and Recrystallisation of copper.—Jackson, Hall and Schwope[41] investigated the effects of cold rolling and annealing on tough pitch high conductivity copper, OFHC copper and OFHC copper to which 0·05% of silver had been added, and found that all three gave almost the same true stress-strain curve. Annealing tests confirmed the fact that silver retards recrystallisation, and indicated means by which the probable degree of recrystallisation after prolonged periods at relatively low temperatures could be calculated from experiments of shorter duration at higher temperatures.

Fatigue of Telephone Wires.—Last year a symposium was held in Australia on the failure of metals by fatigue and two papers presented on that occasion are of particular interest to the copper industry. Both deal with vibration and fatigue failures in copper telephone wires. Levey and Brett[42] give an experimental and mathematical investigation of the problem, including the determination of the frequencies of vibration causing fatigue failure in different types of joints and terminations. The work, however, did not result in any solution to the problem of eliminating or minimising the effects of vibration in telephone lines. O'Donnell and Bundle[43]

made a statistical investigation of the extent of fatigue failures occurring in 30,600 miles of telephone lines during a period of six months and discussed the incidence of such failures in relation to constructional features of the joints, terminations, etc. They mention the advantage of substituting cadmium copper for ordinary H.C. copper wire, discussing its price in relation to its conductivity, but pay little attention to the large amount of information extant regarding the improved fatigue resistance of cadmium copper over that of ordinary H.C. copper.

Shear Strength.—As relatively little has so far been published regarding the shear strength of copper and its alloys a paper by Cook and Richards[44] on this subject is particularly welcome. The table accompanying gives a few selected data from their work, and is sufficient to show the shear strength properties which may be expected from high conductivity copper and cartridge brass after different degrees of cold work. For the fully annealed material in each case the shear stress was about three-quarters of the ultimate tensile strength and fell to half the ultimate tensile strength in the heavily cold worked condition.

Bismuth in Copper.—It has long been recognised that bismuth is one of the most detrimental impurities in deoxidised copper, leading to severe embrittlement under certain conditions of hot working or after annealing in a critical temperature range: but until recently no serious attempt has been made to elucidate the mechanism by which the embrittlement occurs. Papers by Voce and Hallowes[45] and by Schofield and Cuckow[46] throw considerable light on this intricate problem. Voce and Hallowes found that maximum embrittlement occurred when the concentration of bismuth was sufficient to form a continuous film roughly one atom thick covering the whole of the intercrystalline surface area. At temperatures above 600° C. brittleness tended to disappear, the temperature at which it finally did so increasing with the bismuth content. For this reason, among others, it was concluded that bismuth passes into solid solution in copper as the temperature is raised, in which condition it is relatively harmless. Working with certain of the same materials Schofield and Cuckow demonstrated the presence of discontinuous black films at the grain boundaries of the brittle, but not of the ductile, specimens after electrolytic polishing. Further publications may be anticipated to show how the results of the fundamental investigations may be put into operation in industrial practice. Meanwhile, a patent[47] has been taken out for the elimination of bismuth embrittlement from copper and its alloys by the addition of lithium.

Creep of Aluminium Bronzes.—Aluminium bronzes are much more resistant to oxidation and scaling than any of the other common copper-base alloys, and this emphasises the practical utility of an investigation by Voce[48] of the mechanical properties at elevated temperatures. With the usual aluminium bronzes, containing about 10% of aluminium with or without a little iron, no embrittlement need be anticipated during service at temperatures up to say, 450° C. At temperatures above 565° C. aluminium bronzes become too soft and plastic to be of much practical use. In addition to tensile and notched-bar impact tests at room and elevated temperatures, creep tests were conducted, and it was found that stresses corresponding to a creep rate after 40 days of 10^{-5} strain units per day ranged from 6·3 to 9·8 tons per sq. in. at 250° C., compared with 3·6 to 4·6 tons per sq. in. for tin bronzes and gunmetals. These figures, coupled with their high resistance to oxidation, indicate that the aluminium bronzes are the best of the copper-base alloys for service at moderately elevated temperatures, such as those met with in steam plant.

Tin Bronzes for Extrusion.—The development of the use of tin bronzes of relatively high tin content in the wrought condition goes steadily forward. A further contribution to the subject has been made by Prytherch[49] who determined the optimum condition of casting a bronze containing 8·5% of tin with 0·35% of phosphorus in the form of billets for extrusion. Particular attention was paid to the effects of melting and casting procedure on the distribution of porosity, which might lead to flaws in the extruded bar.

Alloys of Copper and Manganese.—Dean, Long, Graham and Sugden[50] have carried out an extensive investigation of the mechanical properties of copper-manganese alloys in the annealed and cold-worked conditions. The tensile strength of the annealed material containing 2% manganese is 16 tons/sq. in., and this is increased to 24·5 tons/sq. in. when 20% manganese is added to copper, while the elongation shows little variation. The alloys may be hot rolled and can withstand more than 80% reduction by cold rolling, the tensile strength being roughly doubled by 80% cold reduction. Some ageing takes place upon heating cold-worked alloys containing more than 6% manganese in the temperature range of from 150–200° C., but the change in properties is insignificant. Recrystallisation occurs at between 370–425° C., and is unaffected by composition. On the whole, the manganese copper alloys would appear to be suitable materials for general cold working operations, but their properties are not specially attractive.

Though the straight copper-manganese alloys show no important precipitation hardening effects, Frederickson[51] finds that the ternary alloys of copper and manganese with cobalt are susceptible to heat treatment and can be hardened by this means. He examined the range of materials containing from 2–4% of cobalt and up to 15% of manganese, and found their hardness in the fully softened condition to be from 40–55 diamond pyramid numbers depending on the composition. Ageing induced a hardness of 150 D.P.N. for the originally annealed material, or 213 D.P.N. when cold work was interposed between the solution and ageing treatments. The hardening is thus much less than that which occurs in the copper-manganese-nickel system.

Dean and his collaborators[52] have determined the boundary of the *alpha* solid solution of the copper-manganese-aluminium system at temperatures up to 850° C.

Marine Propellers.—Stewart and Williams[53] have reported an extensive investigation of materials suitable for marine propellers. Thirty-two different alloys, mainly in the cast condition, were included, and apart from four ferrous materials all were based on copper or on cupro-nickel. The tests comprised normal mechanical tests together with assessment of corrosion in salt water and the effects of salt water on resistance to fatigue. Cavitation was also explored. The composition of the

alloy which the authors single out as the best all-round material was as follows :—

	%
Copper	28·10
Nickel	66·14
Silicon	3·65
Iron	1·49
Manganese	0·62

This alloy had high strength with fairly good ductility ; it was relatively hard but nevertheless machinable, and the notched-bar impact value was good. The resistance to hydraulic cavitation was as much as two and a half times that of high tensile brass, and the technique of casting, heat treatment and welding appears to be fairly well established in America. Though such an alloy would be more expensive than the normal high tensile brasses used for marine propellers, it is certainly worthy of consideration.

The Annealing of Brass.—Among several papers[54-58] which have appeared on the annealing of brass, that of Jenkins[55] merits particular attention. The work embodied a systematic attempt to overcome the difficulties associated with the bright annealing of brass, due to the high vapour pressure of zinc and to the ease with which it is oxidised. By annealing in a vacuum followed by treatment at a higher temperature in cracked ammonia, specimens free from staining, though having an etched surface, were produced. Whether such double treatment can be regarded as commercially practicable, at any rate for the immediate future, is doubtful, but the matter provoked a lively discussion at the Glasgow meeting of the Institute of Metals.

To be continued.

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A New Wickman 5-Spindle-Automatic Catalogue

A NEW catalogue issued by A. C. Wickman, Ltd., covering their 5-spindle automatics, includes a centre-spread in colour which unfolds to show a skeleton view of the machine construction. From it, the spindle and slide mechanisms, gears and all drive arrangements can be followed at a glance. Related to this, small sketches on the side flaps describe the principles of the patented "Auto-setting" mechanism which is a feature of these machines giving the effect of innumerable cams without cam-changing.

MAGNESIUM AND ITS ALLOYS

A Review of Technical Progress During 1947

By R. G. Wilkinson, B.Sc.

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During the year there has been steady progress in the development of new applications for magnesium alloys and the restoration of those which existed before the war. Products incorporating these alloys are contributing to the export drive. The main factor has been the establishment of suitable ingot production and foundry technique for commercial casting alloys to meet the need for increased production of castings at competitive prices. Wrought alloys continue to comprise a minor proportion of the total output, but the development of new high strength alloys will increase applications involving wrought products. Further notable advances have been made in research and development, particularly in the field of cast and wrought zirconium-containing alloys. This review indicates that the magnesium industry has laid a firm foundation on which to build steadily and progressively.

Production and Usage

THE presence of large stocks of magnesium remaining from war production and the national shortage of power and fuel combined to make it expedient to suspend primary metal production in the U.K. early in 1947. Nevertheless, despite the difficulties of the transition period, the past year has seen a steadily increasing usage of magnesium alloys in the U.K. It is probable that total consumption within the year will be around 4,000 tons, which is approximately three to four times that of pre-war years for commercial purposes.

Consequent upon the successful refining of scrap and development of commercial grade alloys to sell at lower than pre-war prices, the costs of Elektron castings, piece for piece, are competitive with those of corresponding aluminium-base alloys. Great interest has, therefore, been aroused in most industries, particularly among the commercial vehicle, electrical and machine tool manufacturers. In addition to the lower prices and the reduction in weights, it is realised that considerable savings can be made in machining costs due to the very high speeds at which Elektron castings can be machined.

In the U.S.A., where war-time magnesium production was measured in astronomical figures, there is still an excess of supply over demand, despite the closure of most of the extraction plants soon after the war. This trend receives confirmation from a report that the Dow Chemical Company were to shut down their Texas plant only about two months ago. As in the U.K., large stocks of primary metal and alloys were built in the U.S.A. during the period of peak production, and it is probable that a large proportion of the estimated total consumption in 1947 of magnesium alloys—about 11,000 tons—will have been composed of metal from store and secondary alloy from reclaimed scrap.

Both here and in the U.S.A., wrought products still comprise only a minor fraction of total output; indeed, this fraction has diminished over the past year, particularly in this country, as the result of increased production of castings and further restriction of aircraft programmes. The present proportion of wrought alloys probably lies between 5 and 10% of the total, but growing aircraft use of new high strength alloys will again affect this relationship.

Little information is available regarding metal production in other countries, but it is certain that small quantities are being made in France; the iron curtain prevents any reliable estimate of Russian production; and Canada is not producing any primary magnesium.

Fig. 1.—Elektron transmission casing for the Ferguson tractor (unmachined weight, 52 lb.).

In the U.K., 1947 has been a year of steady progress in the development of new applications[1] for magnesium alloys and the restoration of those which existed before the war, and the products are beginning to contribute to the export drive.

Steady progress has also been made in research and development, and this is marked particularly by advances in the founding of zirconium alloys, and their experimental service in aircraft. Further technical advances have also been made in the wrought zirconium alloy field.

Casting

As already mentioned, from the point of view of volume production of conventional alloys, the main factor in the past year in the U.K. has been the establishment of suitable ingot production and foundry technique for the Elektron "Commercial" casting alloys, foreshadowed in a similar article in this journal in December, 1946. The efficacy of the measures used to control composition, and to ensure soundness and adequate corrosion resistance, can now be said to have been confirmed in the production of many hundreds of tons of castings.

It has been found possible to work to a maximum variation in aluminium content of Elektron "Commercial" of 8·5–9·5%, and to hold copper and silicon

Fig. 2.—Elektron rear axle worm casing (weight, 30¼ lb.).

impurities to a maximum figure of 0·3% in each case. Zinc is kept between 0·5% and 1·5% and the manganese range is 0·25–0·35%. The narrow aluminium and zinc ranges result in consistency of foundry and heat-treatment behaviour, and of mechanical properties. This material is particularly satisfactory in that its mechanical properties are little below those of first grade alloy to D.T.D. specification. This comparison is shown in Table I, which also includes typical figures for a widely used aluminium-base alloy, D.T.D. 424.

As well as being one of the largest in volume of production, one of the most notable current applications for Elektron "Commercial" alloy castings is their use in a well-known tractor which is being made in very large numbers and allocated for export. Fig. 1 is a photograph of the transmission casing, having an unmachined weight of 52 lbs. Other production castings for the commercial vehicle industry are illustrated in Figs. 2 and 3.

In the field of textile machinery, amongst other applications, there is every indication that Elektron warp beam flanges, such as those depicted in Fig. 4, will prove successful in service and be used widely.

A series of informative articles dealing with most aspects of the production and usage of sand castings has been published by Partridge.[2]

Further to the above brief consideration of sand casting, some progress has been made in the more extensive application of gravity and pressure die-castings. A useful account of die foundry technique has been given in another publication by Partridge.[3] American practice in sand and die-casting has been summarised in two articles by Gray,[4] which also deal with aspects of design and supplement earlier publications on this important subject; and Erickson[5] has reviewed pressure die-casting of magnesium and aluminium-base alloys. Typical pressure die-cast components are illustrated in Fig. 5.

Sand and die-castings to the appropriate D.T.D. specifications have continued to give good service in long established applications in aircraft, and their satisfactory performances have now been confirmed in a number of relatively new applications, such as jet engine components, an example of which is illustrated in Fig. 6.

Willmore and Peterson[6] have carried out a useful series of tests relating to ignition hazards in the heat-treatment of castings in aluminium and zinc-containing alloys.

In addition to the progress which has been made in the production and application of castings in the established alloys, an advance has also taken place in the field of new compositions. It can now be reported that the zirconium-containing casting alloy Elektron Z5Z[7] has passed into routine foundry production, and the alloy has been accepted by the aircraft companies as a material of sufficiently interesting properties to justify service trials, now in progress.

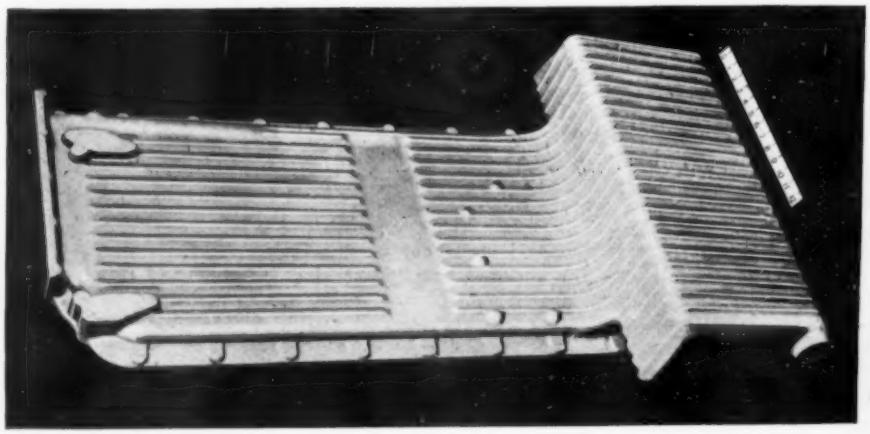

Fig. 3.—Elektron oil sump, weight, 31 lb. (124 lb. in cast iron, 50 lb. in aluminium).

TABLE I.—Tensile Properties of Sand-cast Alloys Elektron A8 (D.T.D. 59B and 289A), Elektron "Commercial" and Aluminium Alloy D.T.D. 424 (D.T.D. Test Bars)

	Elektron A8		Elektron "Commercial"		Aluminium Alloy
	D.T.D. 59B	D.T.D. 289A			D.T.D. 424
	As cast	Solution treated	As cast	Solution treated	As cast
0·1% P.S. tons/sq. in.	4·5–5·5	4·5–5·5	4·0–5·5	4·0–5·5	4·0–5·5
U.T.S. tons/sq. in.	9·0–11·0	15·5–17·0	8·5–11·0	13·0–15·0	9·0–11·0
El% on 2 in.	3–5	10–15	2–5	6–10	2–3

Growing interest has also been evinced in Elektron MCZ[7] alloy, designed for elevated temperature work and particularly adapted to heavy duty applications in I.C. and jet aircraft engines.

Three important characteristics of Elektron Z5Z when compared in certain castings with its established counterparts in the aluminium-containing range, are closer conformity between test bar properties and those of the casting, uniformity of properties within the casting and, in many cases, an overall reduction in tendency to microporosity. Table II presents comparative tensile data for Elektron Z5Z and solution treated A8 obtained from test pieces cut from test castings (Fig. 7) specially designed to determine the above characteristics, and also from D.T.D. test bars. In the case of Z5Z, the test bar figures were obtained from bars poured together with the castings. In the case of A8, ranges are given since the test castings were taken at random from stock.

In addition to uniformity of tensile properties, the combination of high proof and ultimate stresses with good elongations will be noted. A draft D.T.D. specification for Z5Z is in preparation, and the proposed minimum properties for the heat-treated and " as cast " conditions are given in Table III. The good combination of properties in " as cast " Z5Z should prove attractive in cases of castings requiring good ductility, but which could not be solution treated if made in A8 owing to danger of distortion.

The zirconium alloys are, of course, notable for their fine grain size which is inherent in the alloy and does not have to be produced by any special superheating or other treatment: this is illustrated in Fig. 8.

TABLE II.—Comparison of Tensile Tests on Pieces Cut from Casting GR14, in Elektron Z5Z and A8 (Test Bars 0·205 in.–0·359 in., Gauge Length 0·8 in. or 1·25 in.), Together with D.T.D. Test-bar Figures for Each Alloy

Elektron Z5Z: Heat-treated 16 hours at 200° C.
Elektron A8: Solution treated 8 hours at 385° C. plus 16 hours at 415° C.

Mark	Z5Z			A8		
	0·1% P.S. ton/sq. in.	U.T.S. ton/sq. in.	El% / 4√area	0·1% P.S. ton/sq. in.	U.T.S. ton/sq. in.	El% / 4√area
A ..	9·0	17·7	12·5	4·5	16·5	12·5
				4·5	16·0	13·5
				4·1	16·3	10·0
				4·4	16·3	12·0‡
C ..	9·2	17·3	7·0	4·8	9·5	5·5†
				4·2	9·4	4·0†
				4·0	8·9	3·0†
				4·3	9·3	4·0‡
D ..	9·9	18·9	13·0	5·4	13·7	7·5
				5·3	14·8	7·0
				5·4	13·9	6·5
				5·4	13·1	7·0‡
L ..	9·3	18·4	12·5	3·7	10·8	12·5†
				3·7	9·7	4·0†
				4·3	16·8	12·5
				3·9	12·4	9·5‡
M ..	9·7	18·5	12·5	5·0	10·7	5·0†
				4·0	10·5	4·0°
				4·3	16·1	12·5
				4·4	12·4	7·0‡

° Fractured outside gauge length.
† Microshrinkage.
‡ Mean of three values.

D.T.D. Test-bar Properties

	Condition						
3	as cast	6·5	14·5	9·0	4·5–5·5	15·5–17·0	10·0–15·0
4	as cast	6·0	15·6	13·0			
1	heat-treated	9·0	17·6	7·5			
2	16 hours	9·0	17·2	7·0			
5	200° C.	8·8	18·1	9·5			
6		9·6	18·3	8·9			

Test figures for Z5Z are from test bars cast together with the test castings.
Test figures for A8 are typical ranges.

Further test work has been, and continues to be, devoted to Elektron MCZ which contains 0·7% zirconium and 3% rare earth metals, and further creep tests have confirmed the promising results first obtained by Murphy and Payne.[8] In addition to high-temperature creep properties which compare favourably

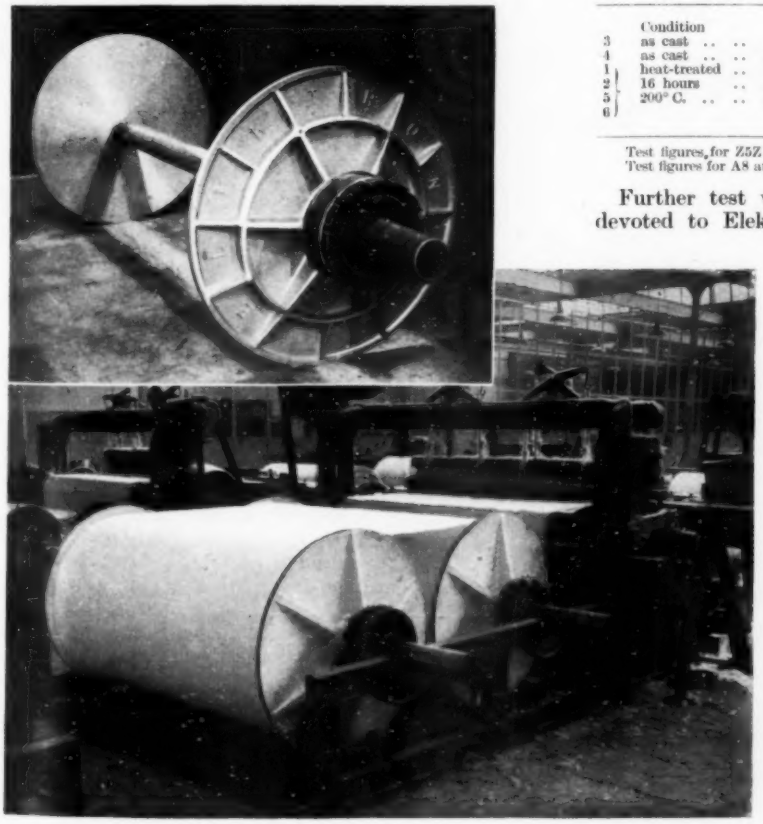

Fig. 4.—Textile warp beam flanges made as sand castings in Elektron " Commercial " alloy.

Fig. 6.—Rear blower casing for a Rolls Royce jet engine.

Fig. 5.—Typical pressure die-castings in Elektron

1 Pirns for textile industry.
2 Hair-drier casting
3 Other typical castings.
1a Parts of precision enlarger.
2a Binocular body.
3a Other parts of precision enlarger.

with those of the aluminium-base alloy D.T.D. 133C, experience has shown that MCZ has good casting characteristics, and, since it shows but little tendency to microporosity, it is well suited to pressure-tight castings in which high ultimate stress at room temperature is not a primary consideration.

TABLE III.—Proposed Minimum Tensile Properties in the Draft D.T.D. Specification for Sand-cast Elektron Z5Z

	0·1% P.S.	U.T.S. (tons/sq. in.)	El% on 2 in.
Heat-treated ..	8·5	15	5
As cast	7	13	7

MCZ is remarkable in that its ultimate tensile stress remains constant (or may even increase) up to a temperature of 200° C.: whilst – for magnesium alloys – its unusually high creep resistance enables it to be used under loads approaching its proof stress at operating temperatures up to 200° C. (0·1% P.S., 4·8 t.s.i. at 200° C.). As is well known, the elevated temperature proof stresses of magnesium alloys which do not contain rare earth metals cannot be used in design practice, since serious creep sets in at stresses far below the proof.

Working

There has been a contraction in demand for wrought magnesium alloy products, particularly sheet, in both

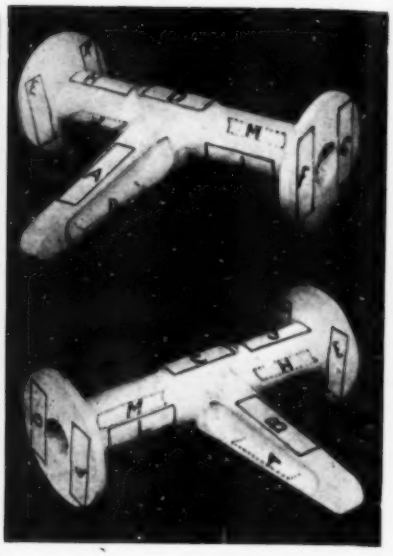

Fig. 7.—Test casting GR14.

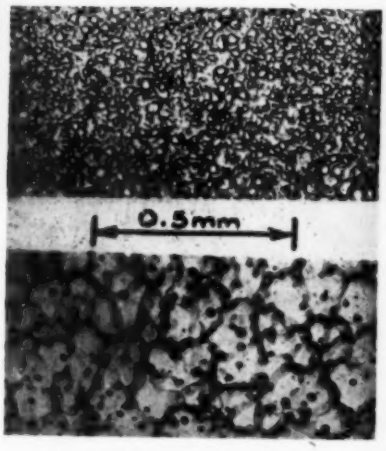

Fig. 8.—Comparison of the structure of die-cast Elektron Z5Z (above) with superheated Elektron A8.

the U.K. and the U.S.A. following the restriction of aircraft programmes. Progress in establishing usage in other directions is proving slow, owing to high costs as compared with aluminium alloys. It can be said, however, that continued experience in the working of the zirconium-containing alloys has indicated that processing costs in scale production could be cut appreciably as against the established alloy compositions.

Although the mechanical properties of the wrought zirconium alloys in most cases show substantial improvements over those of the standard alloys, a comparison with the newest strong aluminium-base wrought materials is not so favourable as it is in the cast field. Nevertheless, considerable interest is being shown in wrought zirconium alloys, and the Planet Aircraft Co. is at present engaged in building a 4–5 seater passenger aircraft almost entirely in Elektron Z3Z.

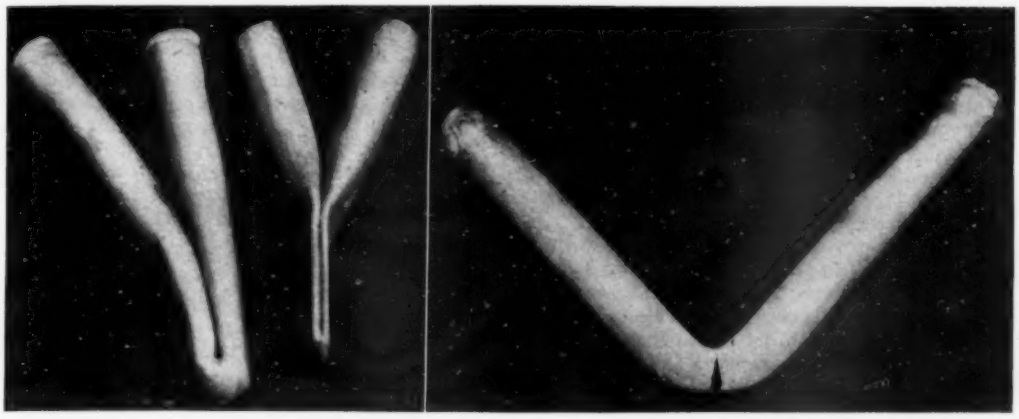

Fig. 9.—Comparison of hot-bending performance of extruded tube in Elektron Z3Z and AZM. The Z3Z tubes could be flattened (filled or unfilled) after bending, but the AZM fractured at about 90° in bending over a 1 in. radius. Temperature was 200–250° C.

Turning to the standard alloys, a not unimportant step forward has been taken in the issue of B.S.[9] and revised D.T.D. specifications[10] which include some tighter compositional limits and improved mechanical property minima. In addition, two new D.T.D. specifications[11] have been created.

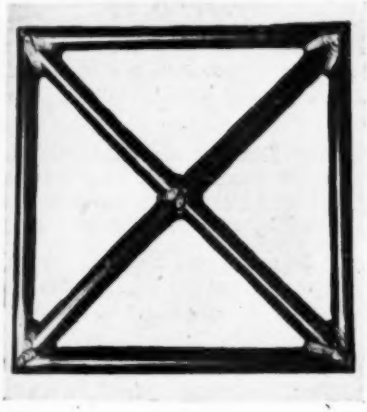

Fig. 10.—Argonarc welded framework in Z3Z tube.

Casting of Stock for Working

In parallel with aluminium-base alloy practice, there has been a trend over recent years to adopt the direct chill (D.C.) casting process for production of rolling slabs and extrusion or forging billets. It can now be said that this process has reached something approaching universal application both in the U.K. and the U.S.A.[12] M.E.L. has been operating a small D.C. plant for some years; it has been found that the newer alloys present no special difficulties.

Rolling

It has already been mentioned that introduction of the zirconium alloys may be expected to lead to a reduction in processing costs. Continued development of sheet rolling has confirmed that the use of large D.C. cast Elektron Z3Z or other zirconium alloy slabs, with appropriate mill process planning, can give high recovery efficiencies of the order of 60–80%, according to gauge. The excellent hot-rolling characteristics of Z3Z leads to shorter, and therefore more economic, rolling schedules. Mention was made in last year's review of the successful experimental application of steel mill cogging and section rolling practice to the zirconium alloys. It has not yet been possible to apply this in scale production owing to plant not being available. It is significant that extensive sheet rolling has confirmed the desirability of using the heaviest possible reductions: indeed, far greater hot reductions can be used on zirconium alloys than those for which existing plant is suitable.

The Americans have also been making great efforts to cheapen sheet production, and the Dow Company[13] has described experimental rolling on a large continuous mill.

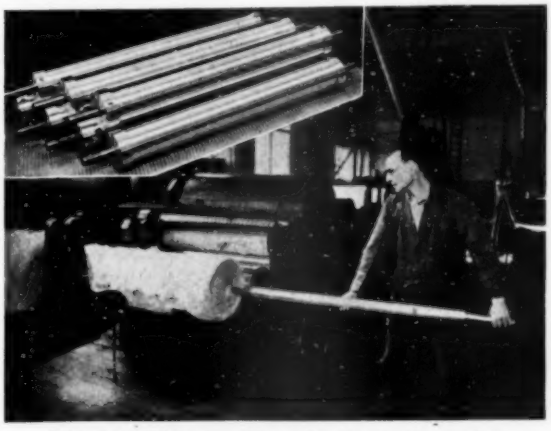

Fig. 11.—Elektron slip roller in service and a number of yarn polishing rollers, made from Elektron AZM extruded tube.

Extrusion

Doan and Ansel[14] have published the results of a well-designed and comprehensive investigation of the extrusion characteristics of the magnesium-zirconium-zinc alloys. Their results confirm (and, to some extent, extend) those which M.E.L. has accumulated during the last seven years.

Extrusion of the zirconium alloys has now been extended to tube in recent experiments, which have indicated satisfactory extrusion behaviour, and strength properties considerably in advance of those for the established "strong" tube alloy-Elektron AZM (D.T.D. 348A). It appears that 0·1% proof stresses in the range 14–17 t.s.i. are obtainable, as compared with a figure of about 9–10 t.s.i. for AZM. Hot bending and argonare welding tests on the tube have also given good results. Fig. 9 shows the comparison between Z3Z and AZM in bending performance at 200–250° C. Fig. 10 shows a typical argonare welded framework made in a series of tests designed to show up any undesirable characteristics, but which, indeed, showed the zirconium alloy Z2Z to be better than AZM in overall performance. Further development remains to be carried out on this subject, but the present position seems very promising.

Extrusions in the conventional alloys are still finding new applications. One which is proving successful in the textile industry is illustrated in Fig. 11.

To be continued

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Staff Changes and Appointments

Mr. G. T. King, at present contracts manager of the Metropolitan-Vickers Electrical Co. Ltd., will succeed Mr. J. Billington as the Company's purchasing agent, on January 1st, 1948. Mr. Billington, who is retiring on December 31st, 1947, after 45 years' service with the Company, has been primarily responsible for the supply of material to the Trafford Park Works for nearly 30 years, during which the dislocation caused by two wars has left a legacy of world shortages and controls. Mr. King's assistant, Mr. H. Lawson-Jones, M.C., B.Sc., will become manager of the Contracts Department.

Mr. E. S. Bailey and Mr. G. C. Downing, of Specialloid Limited and The Aero Piston Ring Company Limited, respectively, have been appointed to the Board of Specialloid (Canada) Limited, Mr. E. S. Bailey in the capacity of vice-president and Mr. G. C. Downing as director and general manager.

Mr. R. P. Horlock, B.Sc.(Eng.), A.C.G.I., M.I.E.E., formerly manager of the Metropolitan-Vickers Sub-office at Leeds, has been appointed manager of the Company's District Office at Sheffield, on Mr. R. G. MacLaverty relinquishing his duties. Mr. W. H. Bill has been appointed to succeed Mr. Horlock as manager of Leeds Sub-office, which is now attached to the Sheffield District Office of the Company's organisation.

Mr. J. Dearden, M.Sc., A.M.I.Mech.E., has been appointed acting chief metallurgist of the London, Midland and Scottish Railway. He succeeds Dr. H. O'Neill, who recently resigned the position of chief metallurgist to take the Chair of Metallurgy at Swansea University. Mr. Dearden graduated at Manchester University with honours in metallurgy and has considerable practical and research experience; he is the author of several scientific papers and of a book entitled "Iron and Steel To-day."

Mr. Nathanael V. Davis has been elected director and president of Aluminium Ltd. on the resignation of Mr. Edward K. Davis, who has been director and president of the Company since its organisation in 1928, in 1945 completed 42 years of connection with the aluminium industry in North America and international fields. Mr. Nathanael Davis, the new president, graduated from Harvard College, later taking special courses at the University of Grenoble, France, and the London School of Economics. He joined Aluminium Ltd. in 1939 and, apart from service in the U.S. Naval Air Force, has since been continuously associated with subsidiary companies of Aluminium Ltd. He is now managing director of Stand Ltd., London, in charge of the Company's British interests.

Mr. C. F. Russell has been elected Chairman and managing director of Specialloid Ltd. following the retirement of Mr. H. N. Bates, and Mr. L. H. Maidman, secretary, Mr. H. R. Peters, general sales manager, and Mr. R. A. Cuthbert, general works manager, have joined the Board.

Mr. Granville Pollitt, formerly associated with the Anglo Iranian Oil Co., at Abadan, and later with the Townend Foundry Co. Ltd., has taken up a post as foundry executive with Kay and Co. Ltd.

Mr. J. W. Weaving has resigned his position with Kent Alloys Ltd., Strood, Kent, to take up the post of foundry manager with Messrs. William Cottis and Sons Ltd.

Mr. Colin W. Roberts, B.Sc., A.I.M., has resigned his position at the A.I.D. Test House, Harefield, and is now at the Research Department of the National Smelting Corporation Ltd., Avonmouth.

Mr. E. Hunter, recently foundry manager of Cannon Ironfoundries Ltd., and previously connected with John Harper and Co., has been appointed manager of the Foundry Equipment Department of Incandescent Heat, Smethwick.

Correction

Under the heading Staff Changes and Appointments on page 28 of the last issue of this journal, the announcement was made in error that Mr. M. K. Haldar, M.Sc., had resigned his position at the Research Department of the London, Midland and Scottish Railway Company. We have been advised that Mr. Haldar has never been employed by the L.M.S. Railway. The facts are that Mr. Haldar was recently afforded facilities for training in the Scientific Research Department at the request of the High Commissioner for India, and thus any suggestion of resignation has misleading implication. The error is regretted.

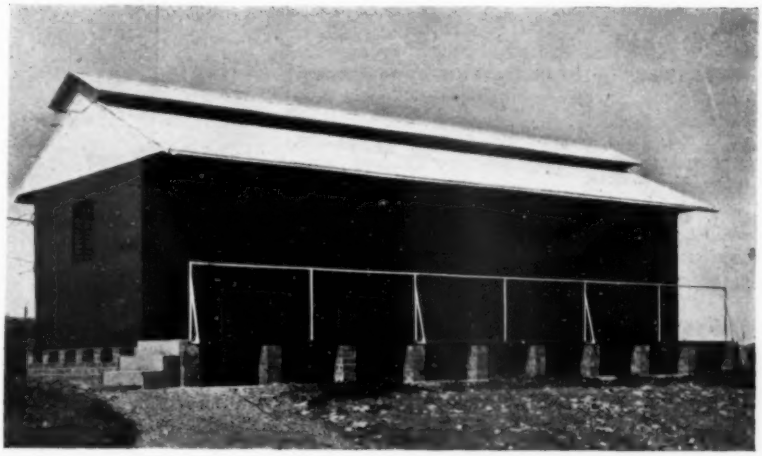
Aluminium Developments in 1947

By Dr. E. G. West

Although considerable metallurgical progress has been made in the development of aluminium alloys and in fabricating technique since the end of the war, the industry has been mainly concerned in re-establishing and extending uses for this material in order to apply its greatly increased production and fabricating capacity. As will be noted, this review is concerned with widening applications in buildings and building appliances, mining, railway and road transport, agricultural implements, and in marine work.

AT the present time it is of more than passing interest to look back for a moment to the time nearly three years ago when the aluminium industry, like others, was considering how and when it would not only regain its pre-war markets but establish new ones. The great increase in production of virgin metal, the new attitude towards the refining and further use of scrap, and the great fabricating capacity built up in this country had resulted in an industry many times greater than existed in pre-war days and it is of value to take stock of the present position whilst further moves are being planned.

Published statistics about the aluminium industry show that a high output of semi-finished forms has been maintained throughout the year and a high proportion of the metal and its alloys has been used in applications that are both new and permanent. Some 40% has been taken for the aluminium bungalow—temporary only in name, but permanent by design and capable of transportation to fresh sites as re-planning and reconstruction proceed.



(*Courtesy of The Bristol Aeroplane Co. Ltd.*)

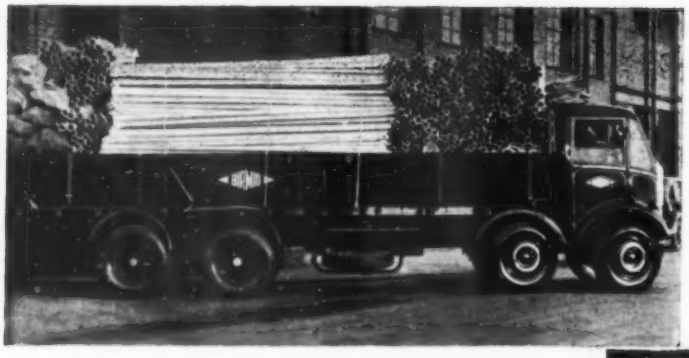
Fig. 1.—An all-aluminium bungalow designed for export to tropical countries.

The aluminium house pointed the way to many hitherto untried applications of aluminium in permanent buildings and to-day it is significant to note that the use of aluminium in building has outstripped its use in transportation according to figures recently provided in America—a notable change in the past eight years.

To the majority of people connected with the building industry, the first indication that aluminium alloys were suitable for structural portions of houses was the announcement of the aluminium bungalow, some 40,000 of which have been produced to date. Although this bungalow represents the highest degree of prefabrication of dwellings yet achieved anywhere in the world, it is not suggested that this form of construction is necessarily the most economical for normal building although several prototype two-storey permanent houses constructed chiefly of aluminium alloys have been erected. Lessons learned from the aluminium house programme so far, however, are definite pointers to the manner in which the more extensive use of aluminium can be effected in houses and other buildings produced on conventional lines.

For example, a great deal of investigation has been carried out into the design and production problems involved in the manufacture of a factory-made roof incorporating both structure and covering, of structure alone, to be clad with more conventional roof coverings. It is important to remember that prefabricated roof trusses are made in factories ready for erection with a minimum amount of labour on the site, thus releasing skilled building operatives for other items in the building programme. The low weight which reduces transport and handling costs, and the high resistance to corrosion which reduces maintenance, are important factors which influence the economic suitability of aluminium alloys for structural work of this kind.

Turning to other developments in the field of building, several lines of progress may be noted—an increase in the use of aluminium for windows, including further work on sliding sash types; the entry of aluminium alloys into what is generally known as "builders' ironmongery and hardware" such as (hinges, etc.); the general acceptance of aluminium sinks and draining boards often built into excellently designed and constructed cabinets; and the rapid absorption of aluminium alloy rain-water goods of all kinds. The British Standards specification for cast aluminium rain-water goods is almost completed and much work has proceeded on gutters and the like fabricated from sheet. The low weight has made these items particularly popular with operatives and it is equally certain that the small amount of maintenance will, in due course, make them popular with house-owners.



(*Courtesy of Birmid Industries Ltd.*)

Fig. 2.—This load of aluminium rain-water gutters, down-pipes and fittings totals some 2 miles and strikingly illustrates the low weight.

Aluminium roof coverings have been applied, perhaps, on a wider scale abroad than in this country and there has recently been described several large-scale applications abroad. For example, some 60,000 sq. ft. of pre-formed aluminium sheet has recently been used for a new roof of a large building at Salt Lake City. The metal of this roof is 0·032 in. thick, comprising 188 sections (128 radial and 60 straight) which were pre-formed and curved in the factory sufficiently accurately to avoid any additional bending of the sheet or extrusions on the site. The original roof was removed and the wood lining covered with tarred felt attached by aluminium alloy nails. The pre-formed sections were then laid with the use of 20,000 sq. ft. of extruded aluminium battens and caps 0·051 in. thick. These battens were fastened with aluminium wood screws and the pre-formed sheets were interlocked to ensure protection against leakage.

In France, aluminium in all forms is being used very extensively for reconstruction of buildings damaged or destroyed during the war. Coiled strip applied direct to timber roofs, corrugated and plate sheets for timber and aluminium frame works, and aluminium interlocking tiles and shingles all being used.

In this country, aluminium has been applied to factory roofs about which more details will become available in due course. It may be mentioned, however, that results from the point of view of corrosion have been extremely satisfactory to date and there is little doubt that correctly selected aluminium alloys can be used for such applications without any protection, other than the natural film of oxide which forms on exposure to the atmosphere. Particular emphasis should be laid on the value of aluminium alloy glazing bars, many installations having now seen twelve to fifteen years' service in a variety of sites, including exposure to industrial and marine atmospheres.

Another large-scale building application which is well established abroad, particularly in U.S.A., but which has not reached any considerable dimensions here, is fabricated aluminium ducts for heating, ventilating and general air conditioning. The low weight of the metal is particularly valuable in erection since it allows large shop fabricated units to be handled by one or two operatives, thus enabling more accurate fit-ups to be made than would be possible if such work had to be carried out on site. Either commercial purity aluminium or the low strength alloys are used and a variety of finishes may be applied in cases where it is not advisable to leave the metal in the bare condition. The usual shop methods employed for fabricating duct work in other metals appear to be used, including the formation of locked seams. Welding is, of course, extensively used for joining, as also is riveting, but self tapping screws do not appear to be recommended owing to their tendency to loosen during subsequent handling of the assemblies.

Considering purely structural applications

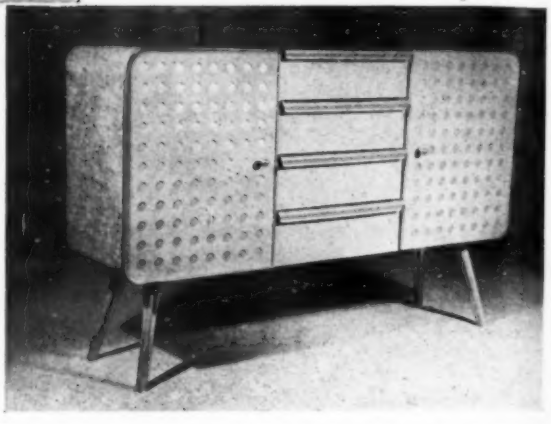


Fig. 3—4 ft. 6 in. sideboard in burr birch and aluminium, designed by Clive Latimer, made by Messrs. Heal and Son Ltd., London. Selected for the "Britain Can Make It" Exhibition.

it is apparent that although a great deal of preliminary investigation and some detailed work is in hand, there are few large structures at present going forward other than the River Wear bridge and a number of large-span heavy duty cranes. Light structures, however, are being adopted for a variety of purposes, an interesting example being the Exhibition Buildings produced at short notice for the Royal Agricultural Show at Lincoln. Eight standard buildings were erected to cover an area of 72 ft. × 36 ft., a team of men completing the job of erection, installation of exhibits, and other preparatory work, in eight hours, dismantling being accomplished in five and a half hours. A particular advantage which came to light during this work was the exceptional ability of these buildings to accommodate themselves to the uneven ground. A rather similar structural application is for greenhouses where designs have been produced for all types from the small domestic 9 ft. × 6 ft. variety up to the largest commercial erections.

Building Appliances.—With the greater interest being taken by contractors and operatives in the use of mechanical appliances as an aid to increasing production in the building industry, there is an excellent chance for the light alloys to be incorporated into a great deal of the new equipment which will undoubtedly have to be produced. Already aluminium alloys are well established for major components of small power-operated hand tools such as electric drills, and there is little doubt that as apparatus of this kind becomes more widely employed in building the advantages of the low

weight of aluminium will make it the normal choice as the principal material used in such tools.

A significant development of the past twelve months is the use of aluminium alloy tubes for scaffolding and several of the largest scaffolding organisations are now using many thousands of feet of high-strength aluminium alloy tube with forged fittings. At present, aluminium alloy scaffolding tubes are being used in approximately the same manner as steel, but investigations are still in progress with a view to combining maximum economy with maximum safety. The alloy recommended for this application is AW.10.C of the STA/7 Schedule, i.e., a magnesium-silicide alloy with an 0·1% proof-stress of 17 tons/sq. in. and an ultimate tensile strength of 20 tons/sq. in. Aluminium alloy scaffold planks are also available and are being produced chiefly as extrusions. Prototype scaffold planks were made several years ago and have been subject to tests and normal usage for a sufficient time to indicate their useful possibilities. Enquiries have been made about other equipment such as wheelbarrows, portable water tanks, brick hods and lifting tackle, and in some cases prototypes have been produced and tested. It may well be expected that the successful use of aluminium alloy shovels in the coal mining industry may result in the adoption of suitable light alloys for tools of this kind in the building and civil engineering industries where the light weight would assist in improving production by reducing fatigue.

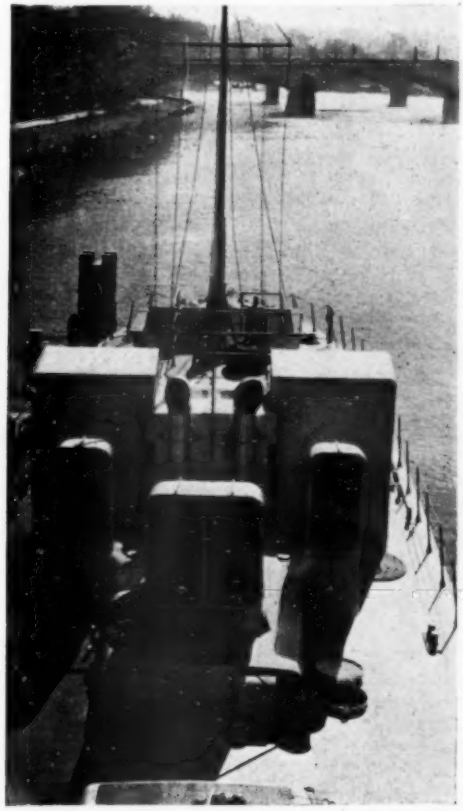
Fig. 4.—A typical heavy lorry panelled throughout with 18G aluminium sheets and including aluminium alloy mudguards, mouldings and roof.

Aluminium alloy shuttering for concrete work has been proved satisfactory over a number of years' experience and considerable quantities are being produced regularly as castings. The action of wet cement mixtures on the aluminium is negligible.

Mining.—The successful application of aluminium to various items of mining equipment has already been described and there is evidence that further experience has amply justified the confidence gained as a result of initial tests. The coal tram exhibited at the British Industries' Fair after a period of service attracted great attention, as also did the other items of mining equipment which had at that date seen and successfully withstood heavy underground duty.

The high resistance to corrosion of the alloys has proved an additional advantage for parts of cages where the rusting of steel due to the damp conditions is sometimes a serious matter. The re-equipment of British mines cannot fail to take account of the advantages of aluminium alloys for practically all items which require to be moved, particularly by the miner underground. Their extended use for all forms of mechanical handling equipment and conveyor parts; switchgear and other electrical components, and for portions of trimmers, etc., would seem to be assured providing there is the necessary close collaboration between the designers and manufacturers of such equipment on the one hand and the aluminium industry on the other.

Railways.—The problems of the railways have received great public attention during the year and there is little doubt that an enormous task of re-equipment awaits the new national organisation. There is already considerable interest in the widespread use of aluminium for railway rolling stock, and experience gained over some two years with a coal wagon plated with aluminium has shown that the unprotected alloy withstands the severe service conditions to a much higher degree than the more usual materials. The next step is to adopt aluminium alloys as the main structural material for wagons and other types of rolling stock, including



(Courtesy of The Bristol Aeroplane Co. Ltd.)

Fig. 5.—Aluminium alloy air outlets, deck stanchions and hand-rails on M.V. "Celerity."

refrigerator vehicles (which has proved extremely successful in U.S.A.), covered wagons of all kinds, fish vans, and vehicles for special purposes.

The experience with aluminium alloy coaches on the Continent and in America has been noted with great interest in this country and there is little doubt that aluminium alloy passenger stock will find its proper place on British railways before very long. It is of interest to note that a considerable amount of aluminium in various forms has been used in the interior of the Golden Arrow now in service to the Continent.

Clearly much of the present interest in aluminium has resulted from the increasing difficulties in obtaining supplies of steel and timber, but there is little doubt that the advantages of aluminium when fully realised by railway engineers as a result of their own experience will lead to their economic exploitation in this industry.

Road Transport.—Steady progress has been made in re-establishing aluminium alloys in commercial goods and passenger-carrying road vehicles in which so much useful experience had been gained prior to the war. The advantages of reduced weight in allowing increased pay load are fully realised and interesting developments have taken place, particularly in the design of passenger-carrying vehicles which are tending more and more towards the stressed skin type of structure. The high resistance to corrosion of properly selected aluminium alloys is an important advantage that has been realised only within the last two or three years by many operators who have been forced to continue running vehicles which would in the normal course, have been scrapped.

Progress has been less spectacular in the motor car industry where the large outlay of man-hours and money in re-tooling for aluminium could not very well be superimposed on the other difficulties experienced by this industry. Cars in the higher price ranges have continued to expand their use of aluminium, both for body work and in the engine, and as new models are designed in each class of private car, more and more attention is being devoted to the possibilities of incorporating aluminium on the widest possible scale. This trend is also to be seen in U.S.A. and on the Continent where, of course, the outstanding example is the "Gregoire" car, the construction of which involves aluminium castings to an outstanding degree.

Agricultural Implements.—British agriculture is another industry in which great efforts are being made to introduce more mechanisation and there are certain outlets for aluminium alloys in this industry in spite of the very low prices which can be paid by the average farmer for new equipment. The technical advantages of aluminium have not been exploited in most types of farming machinery, but with the increasing use of large mechanical devices, such as the combined harvesters, more attention is being devoted to reducing weights in order to assist the operation on certain types of land. Castings are particularly attractive for many components formerly made of cast iron or welded steel and appreciable quantities of aluminium sheet and strip, are already being used with advantage in place of steel sheets and timber. A recent and significant development is the aluminium cowshed designed and built on the unit principle by a West Country concern. The standard units are produced on a framework of formed aluminium sections panelled with double skinned and fluted aluminium. The interior of these combined milking sheds and dairies is left unprotected and bright for ease of cleaning, whilst the exterior surfaces are normally painted grey-green to tone with their surroundings. During the summer of this year, the thermal insulation obtained by the 1 in. air space between the inner and outer panels was sufficient to maintain an even low temperature inside the building.

Aluminium alloy wire is now being used for chain link fencing and to a limited extent in the form of extruded sections for fencing posts. Expanded metal of a suitable aluminium alloy has also found limited use among others as a fencing material, where the higher initial cost can be fully justified on account of the low subsequent maintenance expenditure.

Abroad, aluminium pipes have been used for overhead irrigation of market gardens, orchards, etc., the low weight of these pipes allowing one man to move long lengths to new positions without difficulty.

Minor uses which are being described abroad include poultry houses, feeding troughs and many small items of dairy equipment.

Marine.—Marine applications have steadily progressed chiefly in the small boat field and there are to-day several new lines of dinghies built entirely of aluminium alloy and these are apparently proving popular with the users on account of their low weight, ease of handling and the little maintenance required.

In larger vessels, particular mention should be made of the great success which has attended the introductions of aluminium linings for fish-holds and a full report of this development has recently appeared. There is no doubt that the high resistance to corrosion has contributed largely to the success of this application from the point of view of hygiene.

On still larger vessels, noticeable expansion in the use of aluminium alloy plates and sections for deckhouses, masts, and similar erections has taken place and many of the newest liners are now fitted with aluminium alloy lifeboats as a standard feature. The extension of aluminium to other large items on passenger and cargo vessels, such as hatch covers, is likely, and eventually designing and building of superstructures for the largest ships seems to be assured.

* * *

The year can be, with modesty, described as one of achievement, in spite of fuel and labour difficulties, an embarrassing number of enquiries and more orders than could be dealt with within a normal delivery period. The industry is looking forward with ever-increasing confidence to the future demands which will undoubtedly be made upon it by all the major engineering industries.

Heat-Resisting Alloys of New Type

THE large-scale Swedish producers of heat-resisting metals, the Kanthal Works, have recently put on the market a new type of heat-resisting alloy, called Kanthal Special. This metal, which was described at the annual meeting of the Swedish Metallographic Association some weeks ago, and which has been developed after years of laboratory research, is claimed to possess several new valuable qualities. The manufacturers have succeeded, among other things, in eliminating the brittleness which has previously been observed after lengthy heating at high temperatures. The new metal is reported to have attracted great interest, but owing to difficulties in procuring raw materials, it has so far only been possible to supply about one-third of the demand.

Progress in Powder Metallurgy

By E. J. Sandford, B.Sc., Ph.D., F.I.M.

(Hard Metal Tools, Ltd., Coventry)

It is probable that powder metallurgy was first applied to metals of high melting point, especially tungsten and molybdenum. In recent years it has considerably expanded its field of application, particularly during part of the war period. While the progress this year has not been of a revolutionary character, there is evidence of increasing interest in the application of the process as this review indicates.

ALTHOUGH there has been but little advance in the application of powder metallurgy during the present year, interest in the subject is not waning. As W. D. Jones[1] has pointed out, although the total production in Great Britain is small compared with that in America, a great deal of research is being carried out. Evidence on this is to be found from the first Symposium on powder metallurgy in this country, which was held by the Iron and Steel Institute and the Institute of Metals on June 18th and 19th. A Special Report (No. 38) containing 28 papers covering nearly the entire field of powder metallurgy was published, between 200 and 300 persons attended the technical sessions, and nearly 30 companies exhibited metal powders and products. This may be compared with the Third General Meeting of the Metal Powder Association held in New York on May 27th, at which eight papers were discussed, one film shown, 247 persons attended, and 14 companies exhibited.

In spite of the much greater output of powder in the United States, it is apparent that those interested in the subject are not happy with the progress made at present. For example, Patch[2] considers that the art has made only a minor contribution to production. He argues that, although billions of pieces, mainly porous bearings, have been made, the total weight is only a small fraction of the output of other processes. This " small fraction " amounts to 700 tons of copper and 150 tons of iron powder used each month for mechanical parts and bearings, but Patch considers that progress will be made only when the user of such parts makes them himself instead of purchasing them. There are to-day many companies producing parts by machining which they themselves could produce more cheaply by sintering; nevertheless, other companies prefer to purchase their powder metal parts from specialists.

Production of Metal Powders

The economics of iron and steel components (or, for that matter, of any metal) depends largely on the cost of the powder, and there has, therefore, been some discussion recently on the possibility of reducing present prices. Patch[2] has given the present annual output of iron powder in the United States as 2,500 tons, and Sachse[3] has estimated that the output in 1948 will be 12,000 tons. This is divided between ten plants and the average output of each is around 3 tons per day. Sachse compares this with the average of a blast furnace of 800 tons per day, and draws the conclusion that the prices of iron powder will not fall until units producing 100 tons per day become possible. The production of a powder at 5 cents per lb. cannot, therefore, be foreseen. He also compares the price of powder with the price of fabricated steel such as bar-stock (around $100 per ton) and suggests that too much is expected of the iron powder industry at the present time. It is interesting to compare this slightly pessimistic tone (and that of Patch[2]) with some of the extravagent claims for the capabilities of powder metallurgy for reducing production costs made a few years ago.

The nearest approach to an iron powder at 5 cents per lb. is Swedish sponge iron powder, which is now being imported into Great Britain. The output of this high-grade powder is many thousands of tons a year and economically it is probably the most suitable powder for iron and steel components. Recently it has been improved by the reduction of the oxygen content to 0·7%.[4]

In spite of its higher cost, electrolytic iron is still used for some applications, and the opening of a new plant in the United States, with an output to reach 10–12 tons per day, has been announced.[5] This uses machine shop scrap with cheap electrical power. The scrap is dissolved in acid ferric chloride solution and the iron is deposited on stainless steel cathodes. The solution is re-cycled and the metal removed as a sludge. Gardam[6] has studied the production of electrolytic iron powder on a pilot plant and has concluded that the cost of powder at an output of 1 ton per week would be between 1s. and 1s. 4d. per lb., and even on a large scale, it would be difficult to reduce it below 9d. per lb. That these estimates are approximately correct is denoted by present prices of electrolytic iron powder in the United States,[7] which are between 29 and 37 cents per lb.

Very little has been published concerning stainless steel powder, which aroused interest a few years ago. According to Dale,[8] it is being produced commercially in the United States, and is being used for porous filters. In addition, non-stainless surfaces are being clad with stainless steel powder using a special flux; it is also being used for welding, but no output figures are available, and it is not known whether these new processes are past the laboratory stage.

Comstock and Shaw[9] have forecast the wide use of prealloyed powders which avoid the necessity for alloying to take place during sintering. Such powders can be produced by atomizing, and it is suggested that eventually any alloy which can be melted will be produced as a powder. This, of course, is not a new idea in Great Britain, atomized bronze and other alloys are available commercially, and alloy powders have been used for some years in the production of permanent magnets. The disadvantage is the increased hardness of the grains and the poor pressing characteristics, and the above authors suggest that hot-pressing may be necessary with some of the alloys to obtain a high density.

The testing of metal powders is obviously of great importance in the control of the quality of the sintered product, and Leadbeater, Northcott and Hargreaves[10] have made a careful and detailed study of the testing of commercial iron powders. Particular attention was paid to the flow test, and it was found that the time of flow is directly proportional to the weight of sample, and inversely to the nth power of the radius of the orifice, where n has an average of 2·58. The authors also draw attention to the difficulty of measuring the size of irregularly shaped particles and to the technique established by Martin who took the equivalent diameter as the distance between opposite sides of the particle measured on a line which bisects its projected area. The recommended techniques were then applied to the study of 28 commercial iron powders, electrolytic, oxide reduced, carbonyl, comminuted and chloride reduced. In general, it was found that the apparent density of electrolytic powders is higher than that of oxide reduced ones, and the latter have a higher specific surface.

The Pressing Operation

The attainment of uniform density through a deep pressing is difficult, and it is, therefore, natural that this operation has been studied in some detail. Burr and Clarke[11] have found that the pressure loss at the centre of long cylinders of electrolytic iron pressed from both ends is approximately independent of the pressure, but increases with increase of the length of the pressing, and Squire[12] found that, at a given pressure, a constant ratio of die wall area to pressing area (W/P ratio) gives the same density for all die sizes, but an increasing W/P ratio causes a linear fall in density. Furthermore, the ratio holds for circular or rectangular dies. Lubrication gives a higher density for a given W/P ratio, and the rate of decrease of density with increase in the ratio is less. The author suggests that the use of the W/P ratio will enable physical properties to be predicted before dies are made.

Most previous workers have considered only the mean density either of the entire pressing or over any given cross section perpendicular to the direction of pressure. However, Kamm, Steinberg, and Wulff[13] have studied the distribution of density throughout the compact, by incorporating a lead grid in the powder which was afterwards radiographed. When pressing carbonyl iron in a cylindrical die the powder flows faster (in the pressing direction) at the centre than at the sides, but there is little lateral movement. The highest density on compacts pressed from one side occurs at the circumference of the face at the pressing end, and the lowest density occurs at the circumference of the opposite face. Thus, at the pressing end, there is a fall of density from circumference to axis, but at the opposite end there is a rise, and for some heights of compact, the density at the axis is less at the pressing end than at the opposite end. An increase in the height of the pressing increases the variation through the compact and the density on the axis at the pressing end becomes greater than at the opposite end. Increasing the pressure also increases the non-uniformity. Other powders such as coarse and fine electrolytic and reduced oxide iron powders, gave essentially the same results.

Pressing in a vacuum offers many distinct advantages and a vacuum tablet press has recently been announced[14] in the United States. The feed hopper, die table and punches as well as a receptacle for the pressings are enclosed in a vacuum chamber, and the machine has a maximum pressure of 20 tons. The advantages are that longer pressings can be produced, better powder flow is obtained, the powder fill is less, and risk of cracking is reduced. Perhaps metallurgically, the greatest interest in this press will lie in the possibility of using fine powders which do not flow in air, with the advantage of improved sintered properties. It is understood that it will soon be available in Great Britain.

It is well-known that hot-pressing offers many advantages over the cold-press technique, but so far the difficulties of designing a satisfactory commercial press with permanent dies have not been overcome. Strauss[15] has designed a laboratory press to produce slugs $\frac{3}{16}$ in. diameter and $\frac{1}{4}$ in. long, but carbon dies are used, which, of course, are not economical for commercial production, except with sintered carbides.

Sintered Iron and Steel

A considerable amount of research has been conducted in recent years on the production of iron and steel by the powder metallurgy technique. Apart from the obvious economic requirement every effort is being made to improve the physical properties to compete with more usual techniques, and in connection with the testing of sintered pieces, Squire[16] has pointed out that the properties of specially prepared test-bars may not be the same as those of compacts of a different shape. Sintered parts generally have a low impact strength, and some components have failed in service because of this.

Amongst many studies of the properties of sintered iron, the work of Leadbeater, Northcott and Hargreaves[10] is particularly interesting because the influence of the source of the powder used is clearly shown. These workers sintered compacts (pressed at 30 tons/sq. in.) from 28 commercial powders, some British and some American, at 1,050° C. and found that the range of tensile strengths obtained was from 4·09–20·07 tons/sq. in., with elongations between 1·1 and 8·3%. The best properties were given by a very fine oxide reduced powder which could not easily be used in mass production because of its lack of flow properties, low apparent density, and high volume change on sintering. Finally, these authors give the correlation coefficients between combinations of properties of the powder and the sintered compacts, and it is apparent from the correlation coefficient of + 0·85 between compression ratio and tensile strength that it is difficult to obtain a high strength from a powder of low compression ratio. The correlation between the sintered density and tensile strength was found to be + 0·81.

This relationship has been studied in a different way by Squire[17] who found that curves of tensile strength and density are nearly identical for various powders. This is also true of the impact/density relationship, and he concludes that density can be used as a criterion of mechanical properties, but only if the sintering is correct, since badly sintered compacts, although dense, have poor properties. This work is open to some criticism because the agreement of results for the six powders used is not particularly close. For example, with a density of 7·0 gm./c.c. the tensile strength may vary from 11·6–17·0 tons/sq. in., the elongation from 7–15%, the hardness from 65 to more than 90 Rc–F, and the impact from 7–12 ft.-lbs. according to the powder. It is interesting to note that the ductility and impact strength rise very rapidly with increase of density above

7·5 gm./c.c. Powders of fine grain size give appreciably higher tensile and impact strengths for a given density than do coarser powders, but the elastic modulus depends not on grain size but on density.

The properties of sintered steel have been described often in the past, but several recent papers have added to the available information on this important branch of powder metallurgy. Judd[18] has given detailed consideration to the method of making sintered steel, and has pointed out that the best properties are given by fine powders (which do not flow), high pressures, and perhaps high sintering temperatures. Of the three principal ways of adding the carbon, completely pre-alloyed powders are hard and difficult to press, whereas iron powder containing graphite has the disadvantage that the mixture is easily decarburized and diffusion may be incomplete. Adding the carbon to iron powder as an alloy containing iron carbide has the advantage that sintering may be carried out at or near the iron-carbon eutectic, but the shrinkage is high and dimensional accuracy poor. The author prefers to add the carbon partly as white cast iron and partly as graphite to reduce the quantity of hard powder and assist the pressing. This technique was used during the war to make piston rings.

The formation of steel compacts from mixed powders of iron and graphite has been discussed by Chadwick and Broadfield.[19] The diffusion of graphite is rapid, especially at temperatures above 1,000° C., and ¼ hour at 1,125° C., is sufficient although longer times are required for optimum properties. This is due to the presence of intergranular fissures caused by the diffusion of the graphite, and the time taken to heal these fissures depends on the type and grain-size of the iron and graphite. The authors found that too prolonged mixing of the powders produced continuous films of graphite on the iron and increased the quantity of fissures produced.

The formation of fissures by diffusion of graphite has also been discussed by Squire,[20] who found that a finer grain size of the graphite reduced their extent and therefore increased the strength. A decarburized shotted powder gave higher tensile strengths than electrolytic powder, but this is probably due to the finer grain size of the former.

Stern and Greenberg[21] have recently shown that sintered steel compacts can be case hardened in a salt bath, even though they are porous. Case depths up to 0·010 in. were obtained in times up to 1 hour at 850° C., and the oil-quenched hardness was up to 85·8 Re-15N (approximately 520 V.P.N.). No abnormal corrosion due to the salt was experienced, and provided that the parts are properly cleaned the method should be technically suitable.

Last year, sintered iron-copper received considerable attention in the United States, and this year two papers on this subject were presented at the Powder Metallurgy Symposium, one by Northcott and Leadbeater[22] and the other by Chadwick, Broadfield and Pugh.[23] Both researches show that the optimum properties are obtained with 25% copper. For example, when pressed at 30 tons/sq. in. and sintered for 1 hour at 1,100° C., the tensile strength was found to increase from 9·8 tons/sq. in. with no copper to 32·9 tons/sq. in. with 25%. Chadwick et al. obtained strengths up to 40 tons/sq. in. when the alloy containing 25% copper was pressed at 30 tons/sq. in. and sintered at 1,120° C., but they point out that coarser powders give inferior properties. In fact, under the same pressing conditions, powders of various grain-sizes may give strengths between 10 and 40 tons/sq. in. Northcott and Leadbeater found that sintering below the melting point of copper gives considerably inferior properties, but the disadvantage of sintering with a liquid phase is that large contractions are experienced (up to 12%) and it becomes more difficult to maintain dimensional tolerances. The latter authors also investigated the impregnation of pressed iron compacts with molten copper, and it was found that tensile strengths were a little higher by this method than by sintering previously mixed powders. Furthermore, the contraction during the simultaneous sintering and impregnation treatment was around ½% only, which is of considerable advantage.

Although alloy steels play an important part in metallurgy the same cannot be said of powder metallurgy. Judd[18] has recently stated that it is difficult to produce them other than by using pre-alloyed powders because the melting points of the alloying elements are often high and the rates of diffusion are low; in this respect, a liquid phase during sintering greatly assists.

Magnetic Materials

Permanent magnets have been recently discussed by Garvin,[24, 25] and it is now apparent that this is an established application of powder metallurgy. Although in competition with cast magnets, the magnetic properties of which may be slightly better, the sintered magnet is more economical for small sizes—e.g., up to 1 oz., provided that a large quantity such as 10,000 or more is required. It may also be preferred outside these limitations when mechanical strength is required. Special precautions have to be taken to prevent oxidation of the compacts during sintering, even though pure hydrogen is used, by surrounding the boxes in which they are packed with a metal which has a higher affinity for oxygen than the magnetic alloy itself.

Sintered magnetic iron components and dust cores both require a powder of the highest purity, and the useful properties of carbonyl iron have been discussed by Pfeil.[26] Its packing density is high, it sinters easily into compacts with good mechanical properties; the cost is high, but where a high purity powder is essential it is most suitable. Although magnetic powder cores have been described by Polgreen,[27] Shobert,[28] and Buckley,[29] and although it is interesting to note that 1,000 tons were used during the war, no new developments appear to have occurred in this field recently.

Non-ferrous Metals

Cook and Pugh[30] have studied the sintering of electrolytic, oxide reduced, and precipitated copper powders. It was found that the highest tensile strength is given by the finest powders and by sintering at a temperature just below the melting point of copper. In this case, there is a maximum in the curve connecting strength and pressed density—i.e., the highest strength is not given by the highest pressed density, and, of course, not by the highest pressure in cold pressing. The highest tensile strengths obtained were 11 tons/sq. in. with the electrolytic powder, over 12 tons/sq. in. with the precipitated powder, and only 6 tons/sq. in. with the reduced one.

Bearings still remain one of the most important applications of powder metallurgy and several interesting developments are taking place in this field. Although bronze is the principle alloy, porous bearings of iron or an iron-copper alloy are being used on the Continent and in America, but they are not much used in Great Britain. According to Tait,[31, 32] they have a greater load carrying capacity than bronze bearings at low speeds, but their performance at high speeds is not as good, and they usually cost more to make. A new development is the use of porous bronze plugs in the bearing journal to meter oil from a reservoir to the bearing surface. The sintering of bronze has been studied by Carter and Metcalfe[33] who have determined the inhomogeneity of the α phase by X-ray diffraction, and have found that δ is present when the sintering temperature is below the peritectic temperature of 798° C., unless the time of sintering is unduly long. Above this temperature the homogeneity of the α phase greatly increases.

A new application of powder metallurgy which departs from the usual basic processes is the use of steel-backed copper-lead bearings, recently described by Tait,[31, 32] and Darby.[34] A spherical atomised copper-lead powder, or mixed powders, are spread loosely on steel strip in a continuous operation, and passed through a furnace so that the powder is loosely sintered and bonded to the steel. The sponge is then compacted by pressing or rolling and re-sintered. Finally the bimetal strip is pressed to form bearings, bushes, etc. Various compositions are used according to the precise application.

The application of this process to bronze has been forecast by Tait.[32] Steel-backed porous bronze bearings are to be made by a process similar to that used for the copper-lead bearings, with the advantage that greater strength will be obtained.

Porous compacts are also being more widely used for filters, a subject which has been discussed in detail by Sinclair.[35] In this application, spherical powders of closely graded particle size are required to give a controlled quantity and size of porosity. The application of a highly porous alloy of copper, nickel and tin to aircraft de-icing has recently been made known.[36]

Sintered Hard Metals

There have been no outstanding developments in the metallurgy of sintered hard metals, but these alloys have been discussed recently by several authors and are finding new applications. The preparation of the carbides of tungsten, titanium, and tantalum has been dealt with in detail by Brownlee et al.[37] These authors use a vacuum technique for the carbides of the last two metals, and for the manufacture of the solid solution of tungsten carbide in titanium carbide. This solid solution, which enters in nearly all commercial hard metals used for machining steel, has been investigated by Metcalfe[38] who has found the solubility up to the melting point. The production of the sintered article from the mixed powders (carbides and cobalt) has been discussed by Burden[39] who points out that, owing to the presence of a liquid phase during sintering, the final density is independent of the pressure over a wide range. Sandford and Trent[40] show how sintering proceeds and, in agreement with Burden, emphasise the importance of the liquid phase. They also discuss the constitution of tungsten-carbon-cobalt alloys and show how the structure of the sintered alloys can be related to it. Mantle[41] has investigated the properties of alloys of tungsten carbide with cobalt, and has discussed his results in relationship to earlier publications on the subject. The metallography of these alloys has been briefly dealt with by Kieffer.[42]

The greatest output of sintered hard metals is still used for cutting tools for which application, under the correct conditions, they are supreme. At the present time, however, their useful properties of hardness, wear-resistance, compressive strength, etc., are being used in other fields, and in Great Britain manufacturers are not behind those of any other country in being able to supply large pieces of sintered carbides up to around 24 in. diameter. It is interesting to compare the latest applications in America as discussed by Beardslee[43] with present practice in Great Britain.[44] In both countries, wider applications are being fulfilled in the drawing die field, both for wire drawing and for deep-drawing of such examples as pressure gas cylinders and sheet-metal. The advantages offered are, of course, greatly increased die life and better surface finish. Special hard alloys are being used for the hot extrusion of metals, and the application to punches and press tools is also being met in this country. The punching of steel strip for razor blades can be quoted as one example which is very successful. The use of these hard alloys for high-speed bearings in machine tools was first developed in America, but progress in this direction has taken place in Great Britain. Tungsten carbide rolls for cold-rolling strip, the flattening of round wire, and the forming of half-round wire is another successful application.

Miscellaneous Powder Metallurgy Applications

The powder metallurgy of light alloys has been almost exclusively confined to the production of aluminium powder for applications other than sintered products, although Tait[31] has stated that the manufacture of porous bushes and thrust washers of aluminium is a recent development. They have the load capacities of porous bronze bearings, but show a considerable reduction in weight, and are recommended when aluminium housings are to be used because expansion differences are slight and electrolytic corrosion is obviated. Bickerdike[45] has found that optimum tensile properties are given by an aluminium alloy with 6% copper, with which tensile strengths up to 20 tons/sq. in. and elongations up to 11% are obtainable. It was found that if the sintering temperature was below the eutectic, high pressures were needed to obtain good mechanical properties, but at temperatures above the eutectic lower pressures could be used, but the surface finish was not as good.

Metal spraying using the powder pistol is once again drawing attention, and Jones[46] has dealt with the application of the technique. The most common metal used to-day is zinc, but any metal whose melting point is below 1,600° C. can be sprayed. With the powder pistol, brittle alloys such as cast iron, speculum metal, etc., can be used.

Future Developments

In the course of this review, several projected applications of powder metallurgy have been mentioned, and it is pertinent now to discuss briefly, in more general terms, the lines on which the subject will possibly develop. The production of porous components, refractory metals, hard carbides and permanent magnets are

well established applications. In the field of low strength components (low, that is, in relation to cast or fabricated metals), the technique can offer some advantages, but it is not yet firmly established as an economic procedure except in special cases. Judd[47] attributes the rapid development during the recent war to the difficulty in obtaining machined components, and concludes that the limitations of the process (design and strength) necessitate more development work before it can compete with normal production methods.

Apart from economical considerations, and excluding applications where porosity is required, the possibilities of competing with alloys produced by normal methods undoubtedly lie in improving the physical properties of powder metallurgy products. There is ample evidence to show that properties such as tensile strength, elongation or impact strength depend to a large degree on the density of the sintered piece, and that an increase in such properties will be effected only by an improvement in density. If the future process is based on cold pressing, and if no liquid phase is present during sintering, increased densities could possibly be obtained by an increase in pressure above 50 tons/sq. in. which is approximately the practical limit to-day. To do this introduces obvious difficulties, not least of which is the provision of automatic presses capable of giving higher pressures than at present. An alternative solution to the problem would be to use finer powders, since it is generally found that these give superior physical properties in the sintered condition. But this introduces difficulties of lack of flow properties, and therefore of the inability to fill the dies automatically, and the necessity for a large depth of powder in the die. These obstacles may possibly be overcome to a certain extent by the use of vacuum pressing.

It has been pointed out in this review that the presence of a liquid phase greatly assists sintering and usually permits high densities to be attained with fairly low compacting pressures. Unfortunately the contraction on sintering is usually high and dimensional accuracy becomes low, but a sizing operation could be used with ductile alloys. Furthermore, it has been seen that excellent properties can be obtained by impregnating the pressed compact of the higher melting point metal with the molten alloying metal (e.g., iron and copper). This is a process which offers possibilities because very little shrinkage takes place and it should be possible to maintain a close dimensional accuracy.

Little commercial progress has been made with hot-pressing, except with sintered carbides where mould costs are not very important, but a successful solution of the problems of quantity production would greatly enhance the application of powdered metals to engineering production.

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Hard-Facing Electrodes

RESISTANCE to wear in steel and iron parts has to-day become more important in view of the scarcity of replacements and the need to keep equipment in service longer than intended by the makers. The value of hard-facing electrodes is, therefore, greatly enhanced, and suitable rods are finding much wider application.

Practical applications cover a very wide field, and include: Bulldozer blades in civil engineering; stone-crusher jaws, rolls and mantles and elevator buckets in the quarry industry; cutters and screens in the mines; dredging equipment; slag ladles and mud guns; and metal-to-metal cutting and wearing applications in the aircraft and automobile industries. To meet the requirements of such a wide range of varying wear applications, the "Ardite" range, produced by Hard Metal Tools, Ltd., offers a choice wide enough for most purposes and includes rods containing tungsten carbide, tungsten, chromium, cobalt, molybdenum, zirconium, manganese and vanadium in various combinations and proportions to meet varying wear conditions.

The Cleaning of Metals

II—Alkaline Cleaners

By R. Groves

Although unsuitable for a number of metals and alloys alkaline cleaners probably have the widest range of application for producing chemically clean surfaces. Here are discussed the principal applications of alkaline cleaners, those used for specific operations, and details of operation are also given.

THERE are, as previously stated, a number of metals that should on no account be cleaned with alkaline cleaning materials, because the effect upon them is bad, such troubles as staining, corrosion and spangling being encountered. Aluminium, brass, tin, zinc, and copper, are among the metals concerned, but it should be noted that if the alkaline solution contains an inhibitor, it is possible to use it for aluminium and its alloys, though even then considerable care will be needed. For all the above metals it is sometimes, if not always, necessary to use a non-alkaline cleaner.

Principal Applications of the Alkaline Cleaners

While it is not possible to specify every instance in which an alkaline cleaner should be used, there are a large number of applications for which it is particularly advantageous. For example, wherever, as in electroplating, the metal has to be chemically clean before plating or other processes begin, the last cleaning operation of all should be carried out with the alkaline solution, even when degreasing or the use of an emulsifier has previously prepared the surface to some extent.

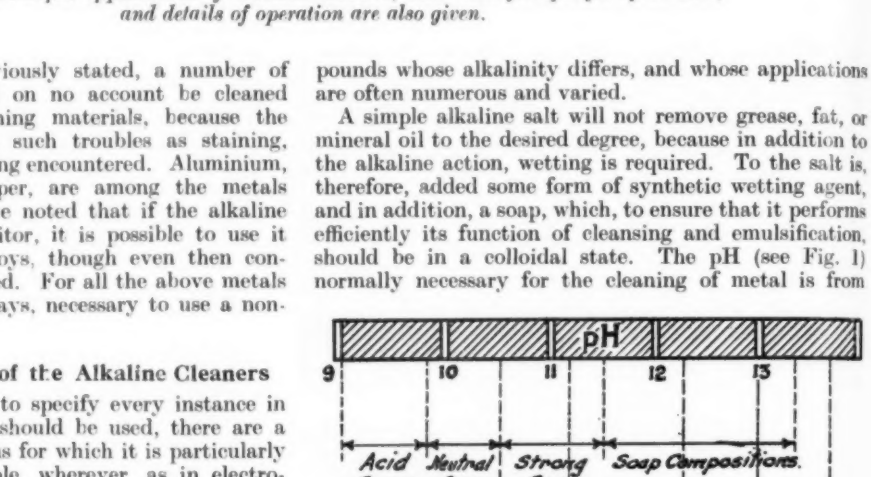


Fig. 1.—pH is the unit of alkalinity of a solution as shown in illustration on the left. On the right is a pH range of cleaning solutions at normal operating concentrations.

Probably alkaline cleaners have the widest range of application of all, and there are few cleaning jobs that they cannot carry out, even though in certain instances they may not be the best for the purpose. One particularly sound application is to the cleaning of complicated large hollow objects. This is because a system of sprays can be arranged whereby the cleaning agent is distributed under pressure in such a way as to eliminate dirt from even the most inaccessible points. Neither solvents nor emulsifiers are so effective in this respect.

The alkaline cleaner is, however, only indispensable for chemically clean surfaces; where the degree of cleanliness required falls short of that, even though it may be very high, it is possible to use the degreaser as long as the treatments given are numerous enough to achieve the desired result.

Types of Alkaline Cleaners

The cheapest type of alkaline cleaning material is almost certainly caustic soda. This lacks many advantages, but is sometimes used precisely because of its cheapness. Compounds of caustic soda are also used, and in succession come a wide range of salts and compounds whose alkalinity differs, and whose applications are often numerous and varied.

A simple alkaline salt will not remove grease, fat, or mineral oil to the desired degree, because in addition to the alkaline action, wetting is required. To the salt is, therefore, added some form of synthetic wetting agent, and in addition, a soap, which, to ensure that it performs efficiently its function of cleansing and emulsification, should be in a colloidal state. The pH (see Fig. 1) normally necessary for the cleaning of metal is from 11·0 (min.) to 13·0 (max.), but the normal soap is incapable at this pH of maintaining the colloidal state, so that the soap used must be of special type.

The oil left on metal parts after they have been immersed in a quenching bath, or after they have been heavily oiled for protection against rust, needs a heavy duty alkaline cleaner, and a special type is made for this purpose, incorporating in its composition a number of added materials to enable it to work successfully.

It would be impossible here to enumerate every different type of alkaline cleaning material, because although the majority of cleaning operations are carried out with a relatively small number of standard alkaline materials, there are numerous operations that require specially compounded solutions. In those instances where a standard alkaline solution does not appear to yield satisfactory results, and it is nevertheless desired to retain the alkaline method, it is advisable to carry out tests on the type of metal to be cleaned, attempting as far as possible to make the conditions of the test match the specific cleaning operation. The best plan in such instances is to choose one or two of the most reliable

makers, specify the problem, including all details, and ask for samples of recommended solutions to be tried out. Such tests are, in the main, needed only for alkaline solutions, because vapour and solvent degreasing solutions and emulsifiable cleaners are less numerous and their suitability for a specific operation is readily ascertained.

Cleaners for Specific Operations

When metals have been drawn or stamped, they are usually coated with a film of lubricant and dirt. Even if absolute chemical cleanness is not required, as the parts may not be required with so good a finish, it is on the whole better to clean them with an alkaline solution. For drawn metal and stampings, as long as these are not of aluminium or zinc, the best type of solution is one of non-caustic type which has a swift and effective emulsifying action on the mineral oils and greases with which the parts will be coated. This type of cleaner is delivered in the form of big white pieces readily dissolved in water, and forming a solution whose working life is of long duration. A cleaner of this type will carry considerable quantities of foreign matter in suspension before beginning to lose potency, so that not only does it give an efficient cleaning, but it is also economical.

The solution is easily washed off after use, and does not tarnish steel, brass or copper. It does not produce a foam, so that it is quite suitable for use in a washing machine, and is employed in the concentration of 1 oz. per gallon of water. This solution, however, operates at a pH which is too high for parts made of aluminium, zinc and their alloys, but it is quite suitable for magnesium alloys. A cleaner of this type is regularly used in cleaning stampings, and drawn parts. Where the output required is inadequate to make the use of a washing machine economical, a modified solution of the same type is used in tanks, and the solution is then prepared at the concentration of 3 oz. per gallon. Steel should be cleaned at a temperature approximating to the boiling point of the solution. Brass is best cleaned at approximately 70° C.

Cleaning Deep-drawn Parts

Deep-drawn parts are often so difficult to clean that one alkaline operation will not suffice. The temperature at which the parts are drawn has the effect of forming a metallic soap from the fatty lubricant, and this is exceptionally difficult to clean off. Sometimes sulphonated oils are used in the drawing operation, and these too are not effectively removed by a single alkaline wash. If left on, however, and the parts are later sent to the annealing furnace, the temperature of the annealing operation causes the dirt to react with the surface of the metal, and so causes a modification of the structure on the surface. It is, therefore, essential that before the part is sent to be intermediately annealed, in readiness for the next drawing operation, this dirt shall be removed. Particularly is this true of the tiny particles of metal present, which are often maintained firmly in place by magnetism.

If the part is required to have a chemically clean surface, then alkaline solutions can be used as the final cleaning agent ; but for these intermediate washings an emulsifiable type of cleaner, either in the form of a spray or as a solution in which the part can be immersed, will be found advantageous.

Cleaning Machined Parts

Machining, cutting, grinding and other machining operations on steel, iron, bronze, copper and brass, as well as magnesium, and its alloys, may need to be followed by a cleaning operation, and an alkaline solution of the type recommended for drawn and stamped parts, either in tanks or mechanically applied, will be found effective. Sometimes, however, steel is polished by means of a grinding compound consisting of a blend of tallow and emery. For its cleaning, the alkaline solution is not effective, and it is, therefore, better to use the emulsifiable cleaner.

A special alkaline cleaning solution must be used for aluminium and its alloys when these have been machined, buffed, or polished, particularly if it is essential that the metal shall retain its original tint, weight and size. This cleaner is employed in still tanks at a concentration of 4 oz. per gallon, but if a machine is used, the concentration should be 1 oz. per gallon. The solution should be used at a temperature of 80° C. in order to ensure that cleaning is carried out efficiently without any risk of corrosion of the metal. The same solution can also be employed for zinc. The cleaner, as used in tanks, is a yellow powder which flows freely and is easily dissolved. The solution used in washing machines is slightly less foaming.

Cleaning Die Castings

The solution or method used depends largely on the type of die casting. If of aluminium or zinc alloy, it is essential to use an emulsifiable cleaner, and the same solution can also be used without difficulty for magnesium alloy die castings. The castings are steeped in or sprayed with the solution, which consists of one part of a special material dissolved in ten parts of paraffin or some form of safe solvent. The castings are allowed to remain for one minute in the solution, and are then drained for 30 seconds so as to waste as little of the solution as possible. The casting is then either rinsed in cold running water, or sprayed. If the castings are to be electroplated, an additional 30 seconds washing in a special alkaline cleaning material designed for soft metals should be given, the solution being at 80° C., after which a further water rinse is followed by a short immersion in 1% hydrochloric acid. For all other die castings it is sufficient to clean with the emulsifiable cleaner.

It is, of course, possible to wash the castings or clean them electrolytically in the alkaline solution, but this consumes more time and invariably modifies the colour of the alloy.

Cleaning Oil-quenched Parts

The oils used in quenching baths are, if regularly used with reasonable continuity, liable to increase in temperature, almost, on occasion, to within a few degrees of their flash point. This is particularly true where care is not taken to keep the bath reasonably cool. In consequence, the oil is liable to disintegrate, and a sludge forms on the bottom of the tank, while some of the oil is carburized and becomes unduly acid. In such circumstances, the quenched part is liable to acquire a coating of exceptionally tenacious character.

The standard type of cleaning material will not eliminate these deposits, and a heavy duty alkaline solution is essential. This must be carefully blended to ensure that it has both the wetting and the penetrating power required, in addition to the rinsing properties of a soap. It should be noted that the number of low titre soaps capable of effective action in a solution of this type is limited.

The type of solution required is, therefore, one with comparatively high alkalinity and the properties of a soap. As cleaning quenched parts necessitates a somewhat protracted immersion in the solution, the normal conveyer type of cleaning machine is unsuitable. The parts are first boiled in the solution for an adequate time, and after this are given a boiling, soaking rinse in water. The period ranges from 15 minutes to 3 hours according to the type and thickness of the deposit to be removed.

Details of Operation

The concentration is 8 oz. per gallon, and the tanks used should be capable of accommodating the parts so as to provide complete immersion. The solution cannot be used in a washing machine because of the readiness with which it foams. Nevertheless, methods can be devised whereby the parts can be handled and the tank treatment with boiling solution given as a stage in the production line.

Because of the high alkalinity of the solution, it is necessary that the operators should be provided with rubber gloves, aprons and shoes, in addition to goggles. Should any of the solution fall on the skin, despite these precautions, the affected area should at once be well washed with water and boric acid or vinegar applied after which a vegetable oil, such as castor oil, should form the final dressing.

The solution should not be used for aluminium and its alloys, nor for brass, zinc, lead or tin, which it corrodes. Copper is slightly stained on the surface, but is not otherwise attacked. Magnesium alloys are not affected.

Sometimes the procedure mentioned is not sufficient to eliminate all the dirty oil, but it should be used if possible because of its economy. Where it proves inadequate, the parts must be steeped for the necessary period at normal temperature in a solution of one part of a specially heavy duty cleaner in eight parts of paraffin. Draining for 30 seconds follows, after which the parts are given a cold water spraying at high pressure. They are then dried with hot water or by means of an air blast.

Further cleaning operations will be dealt with in the next article.

How to Construct a Stress-Strain Diagram by Hardness Measurements*

By N. N. Davidenkov

The basic principles of a method are given which enables the construction of a stress-strain diagram by using the usual Brinell hardness tests and without making an actual tensile test. A new significance is given to this test.

THE specimens necessary for performing tensile tests cause certain expenses and labour. Furthermore, in many instances, such as after accidents, tests, etc., the investigator has at his disposal only some small fragments which do not allow for the production of the necessary standard test specimens. For instance, in the periodical tests of steam boilers, specimens have to be cut out and the hole has to be prepared by riveting a piece of new material which may prove harmful for the strength of the boiler.

It is obvious that a method which would permit the making of a stress-strain diagram by means of two or three different hardness measurements, without any destruction to the part and in a very short time, would be of great practical value, and would in many cases replace other prescribed tests. Such a non-destructive test may be based on the following conditions: Fig. 1 shows schematically the real stress as a function of the contraction of cross-sectional area; the course of this function may be determined by the following four values.

(1) by the yield limit S_s;
(2) by two stresses s_n and s_m corresponding to given contractions ψ_n and ψ_m;
(3) selected arbitrarily on the straight section of the curve;
(4) by the real breaking stress S_k; the contraction ψ_k being not known.

If these four co-ordinated values are given, the diagram can be plotted as follows: We plot the points s_n and s_m for the given values ψ_n ψ_m as abscissae and connect them by a straight line. We draw a parallel line (dotted) in the distance S_k to the abscissa and the intersection with the inclined line gives the contraction ψ_k which limits the diagram to the right hand side. The ordinate at $\psi = 0$ made equal to S_s and this point is connected by a line fitting tangential to the straight line through s_n and s_m; the actual course is of no practical interest.

This diagram allows us to find the following data:—

(*a*) the real tensile strength S_b (not shown in diagram), corresponding to $\frac{1}{2}$ C D (ordinate for $\psi = 1$);
(*b*) the uniform contraction ψ_b, being the abcissa of
(*c*) the temporary resistance $S_b = s_b\ (1 - \psi_n)$;
(*d*) the uniform elongation $\delta_b = \psi_n / (1 - \psi_n)$;
(*e*) the ultimate contraction ψ_k;
(*f*) the maximum elongation $\delta_k = \psi_k / (1 - \psi_k)$;
(*g*) the maximum elongation of the specimen being the sum of the uniform elongation δ_n and of the elongation of the neck δ_n.

The elongation of the neck δ_n may be calculated according to G. Zuitzev's formula (1):

$$\delta_n = \frac{d}{2l}\,(1 - \sqrt{1 - \psi_{kB}})^3 \cdot \frac{3 + \sqrt{1 - \psi_{kB}}}{\sqrt{1 + \delta_B}}$$

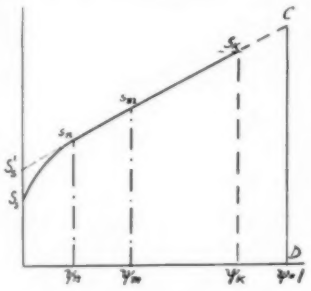
wherein $\psi_{kB} = \dfrac{\psi_k - \psi_B}{1 - \psi_B}$ the final contraction calculated for an equally contracted cross-section.

(*h*) The specified work of deformation being the area of the diagram of real stresses correlated to the real elongation according to Ludwik.

* *Journ. Techn. Physics*, Vol. 13, 1945, p. 389, No. 7–8.

Evidently for designing the diagram four other characteristics could have been used. For instance instead of s_m the coefficient of strengthening upon a rectilinear section (probably the workhardening effect—Ed.) might have been used, and instead of s_k, the extrapolated yield limit S_s (Fig. 1); but these factors are considered to be less favourable.

For the determination of s_n and s_m the experiments of Ludwik[1] may be utilised. Being in the possession of the stress strain diagrams of four different metals (aluminium, copper, brass and nickel) as well as of their indentation hardness by means of a small ball and a cone, Ludwik determined an elongation along the abcissa in such a way that the ratio of hardnesses for these metals were just equal to the ratio of the corresponding ordinates. The indentation hardness values



[1] This diagram is a simplification of that given by Ludwik[2]. This shows an upwards bent of the curve—i.e., the real breaking stress (Reissfestigkeit) does not lie on the straight line shown. Further, the stress for the maximum load Sb is not shown which demonstrates the relation Sb = ½ CD which according to Ludwik has first been observed by Moellendorf and Czochralski in 1913.

Fig. 1.—Schematic diagram of the real stresses in relation to the contraction.[1]

were in these instances determined in such a way that always the same form of indentation was obtained—i.e., d = D/4 or, d = D/2 in the case of the ball with diameter D; in the case of the cone the indentation form is, of course, always the same.

For calculating the stress-strain (elongation) diagram from hardness determinations, it is therefore sufficient to multiply the hardness values with constant coefficients which are equal for all metals: In Ludwik's experiments the following values were obtained :—

Shape of indentation	Ball d = D/4	Ball d = D/2	Cone
Elongation %	9	12	18
Contraction %	8·5	10·7	15·2
Factor for relative stresses	0·40	0·34	0·28
Factor for real stresses	0·43	0·38	0·33

True stress-strain diagrams of various metals show that the two last points are usually situated on a rectilinear sector of the diagram, and therefore each of them may be used for designing the diagram. Further, it is not necessary that the impression is just ¼ or ¾ of the diameter of the hardened steel ball. Since the conversion coefficients do not depend on the kind of material tested, but only on the ratio d/D a general diagram of conversion coefficients as a function of d/D may be developed and for a given d the conversion coefficient may be found.

The stress S_k may be determined by a scratch test similar to that of Martens, only that in this case scratch widths of 2–3 millimeters are more favourable than the fine scratches of say 0·070 mm. and small loads of 50 grams used by Martens. The author[3] has published in 1941 a detailed theoretical and experimental comparison between scratch hardness and other mechanical properties of metals and found a close connection between scratch resistance and tensile strength. The problem has been statistically surveyed using 20 metals from aluminium to soft steel. The scratch hardness Hs has been determined as being inversely proportional to the scratch width produced by a diamond under a load of 50 grammes. For various mechanical properties correlation coefficients have been determined, and the following result was obtained :—

S_k	Ultimate tensile strength	S_n	Elastic limit	H_R Rockwell hardness
0·95[1]	0·72	0·79	0·67	0·75

1 S_k = 0·97 for tests with optimum accuracy.

Since the best correlation is obtained for S_k (real tensile strength) this value has been chosen for further use, and it can be calculated with sufficient reliability from H_s; thus :

$$S_k = 4{\cdot}02/(H_s - 22{\cdot}5) \text{ in kg./sq. mm.}$$

whereby H_s is the reciprocal value of the scratch width in mm. obtained under a load of 50 grammes. This relation, however, applies only for the micro-range and for the macro range with greater width of scratch other empirical constants may apply. The macro-scratch process could be carried out with a relatively simple apparatus.

Finally, the yield limit may be determined according to Tammann and Mueller[4] by measuring the diameter of the deformed zone around the cone (Ludwik hardness test). Then the yield limit is obtained by :—

$$S_p = 4\ P/\pi \cdot D^2$$

with P = load and D = diameter of the zone of deformation; Krainer[5] has shown that this method is sufficiently reliable.

The processes which are necessary to arrive at the results are as follows :—

1. Ball-hardness test according to Brinell; measuring the diameter of the impression, and calculation of the hardness referred to the surface of the impression.

2. Cone-hardness according to Ludwik (under any load) and then producing a horizontal displacement (scratch) of 10–20 mm. (⅜ to ¾ in.) length under the same load; measuring the diameter of the impression under static loading; measuring the diameter of the zone of deformation, and measuring the width of the scratch.

3. From the data thus supplied the values S_s, s_n, s_m and S_k are calculated and the diagram Fig. 1 can be constructed.

Modulus of Elasticity (Young's Modulus)

Another statistical value of metals could be determined in a simplified manner by hardness tests, but in this special instance the dynamical hardness had to be employed. It is a fact that the values obtained in rebound tests do not only depend on the hardness of the metal but also on its modulus of elasticity. With the same height of fall and with the same diameter of impression—i.e., the same plastic deformation, the amount of elastic energy stored in the specimen will be the larger the smaller the modulus of elasticity of the material in question. From this it follows that the relation : height of rebound will also increase with

1 G. P. Sajzew, Inscheneruj Sbornik Otd Tech. Nauk A.N. SSSR 1, No.2, 143, 1941.
2 P. Ludwik, Z.VDI, Vol. 71, 1927, pp. 1532-1537.
3 N. N. Davidenkow Nekotorne problemu mechaniki materialov, P., 1942.
4 G. Tammann and W. Mueller, *Z. Metallkunde*, Vol. 28, 1936, pp. 49–54.
5 H. Krainer, *Messtechnik*, Vol. 13, 1937, pp. 64–68.

reduced modulus of elasticity. When comparing materials of different hardness and different modulus of elasticity one may plot an empirical graph of the rebound height; materials having the same modulus of elasticity can be connected by a system of "iso-elastic" lines. Such a diagram will then allow to determine immediately the modulus of elasticity from rebound data, and it is assumed that the determination will be sufficient for practical purposes.

Appendix 1—Notation

- ψ Contraction (usually with index).
- δ Contraction (usually with index).
- S_s Yield limit, determined by the tensile test.
- S_p Yield limit determined by hardness test.
- s Stress (usually with index).
- S_k Real breaking strength (in the usual stress-strain diagram it appears to be smaller than S_b).
- S_b Real tensile strength (highest load in the usual stress-strain diagram in which the stresses are referred to the initial cross-sectional area).
- H_e Scratch hardness $= 1/\text{scratch}$ width appearing under a load of 50 grammes.
- H_R Rockwell hardness.
- P Load.

Appendix 2—Relation Between True Stress and Breaking-stress

The relations (c), (*d*) and (*f*) can be easily derived. Usually the breaking stress σ_B is referred to the original diameter d of the test bar, whereas the true or real stress S_B has obviously to be referred to the diameter of the bar of the necked test piece d_t, which is related to the original diameter d by the contraction factor ψ_B—i.e.,

$$\psi_B = \frac{d^2 - d_t^2}{d^2} \cdot 100 \quad \text{(definition of } \psi\text{) since } \sigma_B = P/\pi \cdot d^2 \text{ and } s_B = P/\pi \cdot d_t^2$$

with P breaking load, we obtain by introducing these values in the relation for ψ_B after some conversions:

$$\sigma_B = s_B (1 - \psi_B),$$

which is relation (c).

The relations (*d*) and (*f*) follow from the constancy of the volume of the test bar (or a section of it). A length of test bar l of diameter $\overline{l_{d_t}}$; the constancy of volume supplies:

$$l \cdot d^2 \cdot \sigma = (l + \lambda)\, d_t^2 \cdot \pi$$

with $\lambda/l = \delta$, we obtain:

$$d^2 = (1 + \delta)\, d_t^2$$

which can be re-arranged using $\psi = \frac{d^2 - d_t^2}{d^2} \cdot 100$ into $\delta = \psi/(1 - \psi)$—i.e., the form of relations (*d*) and (*f*).

$\overline{l_d}$, has after the test a length $l + d$ and a diameter.

New Developments in the Recording of Oscillograph Traces

IT is known that high speed mechanical or electrical variations can be translated by a standard commercial oscillograph into visible traces on a fluorescent screen. The impermanence of the traces, however, makes difficult any accurate study of the inter-relationship of several phenomena and makes impossible any subsequent checking; and attempts have been made with varying success to photograph these traces by means of standard cameras.

During the late war Messrs. Avimo Ltd. designed special cameras which gave much more satisfactory results and recorded, side by side, on continuous film or paper, traces from any standard type of oscillograph. The number of traces which could be so recorded however, was limited in practice by the fact that the space between the screens necessitated moving the camera back so far that the traces were reduced eventually to an impracticable scale. To provide a record on a practical scale where a number of traces are required to be shown side by side, Avimo now have in production a series of recording cameras with built-in cathode ray tubes—the latter so arranged that their traces are

15-channel camera by Avimo Ltd. which records 15 oscillograph traces side by side.

Photo-cell microphone unit by Avimo Ltd., designed for light and sound measurements.

photographed through a mirror. In this way, as many as 15 traces, plus a timing interval, may be recorded on a scale adequate for practical purposes.

A camera of this type has been incorporated in a photo acoustic recording unit, which has been designed and made to the special requirements of the British Ministry of Supply. It consists essentially of an Avimo 6-channel camera with built-in cathode ray tubes, and 6 photo-cell microphone pick-ups—the latter being suitably placed round a target within a radius of 2,000 feet. The camera, with electronic amplifiers and control equipment, is housed in a van and is connected to the pick-ups by cables. Each pick-up transmits, in the form of electrical energy, both the light intensity throughout the duration of the flash and the sound of the flash—thus enabling, for example, the distance of the flash to be determined.

The reactions of the pick-ups are recorded in the form of linear traces on the six 1½ in. cathode ray tubes (VCR.522), which are built into the camera. The maximum length of trace on each tube screen is 1 in., which is reduced to 10 mm. on the film. Provision is made for the use of standard 70 mm. perforated film or paper in 100-ft. lengths, wound on metal spools, and a microscope is provided which permits the viewing of the traces whilst recording is in progress. The cathode ray tubes are each mounted in a mu-metal shield, so arranged that the light from the tube heaters has a minimum effect on the film, and it is possible, by an adjustment which is not affected by normal vibration and handling, so to orientate each tube in its mounting that the traces lie on *one straight line* on the record, at right angles to the direction of film travel. A range of six film speeds is obtainable, approximately 1, 2½, 5, 10, 25 and 50 inches per second.

Metal Conservation in Europe

Progress of Phosphating

THE method of protecting iron and steel, and to a less degree zinc and other metals, by means of phosphating followed by a finish of paint or varnish or simply by oiling or a chromate rinse, developed rapidly and on a large scale in Germany, Italy, Holland and Russia during the war. As a powerful aid in the fight against corrosion both in itself and also as a very effective bonding agent for paint and varnish its special merits have long been known.

In Italy and Germany it was found particularly valuable in conserving copper, nickel, tin, etc., for these could very often be replaced by phosphated iron. The possibility of replacing tinplate, for example, by black plate or phosphated sheet iron, has been the subject of much experimental work in Germany during the past few years; and is not without interest in this country and in America. Work in Germany has been mostly carried out by one large firm, the Metallgesellschaft of Frankfort, and numerous papers by the research staff of this company have been published in *Korr. u. Metallschutz* and other technical journals in that country up to 1944, covering a whole range of developments in the phosphating process and its applications.

A comparatively recent application is in the metal working field, especially in deep drawing, as an aid to lubrication, a logical development of the property of the phosphate coating in adsorbing and retaining oil. Dürer and Schmidt reported on this in two papers in 1942 and 1944. Somewhat related fields of use are in wire manufacture in the U.S.A., and as a means of preventing scuffing in gears, seizure of piston rings, etc., which formed the subject of a recent report by the Automobile Research Committee of the I.A.E., and again confirmed the value of phosphating in lubrication.

It is hardly necessary here to describe the process, which is comparatively simple, although the underlying chemical reactions are not necessarily so; especially with accelerators, whereby the time required for phosphating may be reduced to a matter of seconds. There are various patented methods, using mainly solutions of iron and zinc or iron and manganese phosphates, with and without accelerators, employing spray, dip, or brush, and sometimes resilient rollers to speed up the work. Known under the names of Bonderising, Parkerising, etc., phosphating is covered in this country and America by numerous patents in the name of the Pyrene Co. Ltd., Parker Rust-proofing Co., and the American Chemical Paint Co., all of whom have carried out research on a considerable scale and continue to do so.

In Italy, as in other countries, it was largely employed in the protection of war material and in facilitating the provision of substitutes for scarce and valuable metals; also as an aid to lubrication in metal drawing, wherein a thin coating by the Bonder method was found very effective. O. Macchia of Turin, in describing recent progress in Italy, notes that as long ago as 1921, J. H. Gravell (subsequently president of the American Chemical Paint Co.) in his U.S. pat. No. 1428087, proposed a thin coating of phosphate on steel before rolling, drawing, etc., in order to reduce risk of corrosion and friction. More recently, that company has taken out other patents for the same purpose, e.g., Eng. pat. 512594. Reference may also be made to the Italian patents of the Metallges. Akt. Ges. Nos. 362750, etc., and of F. Singer 365555 and 365592 (Eng. equiv. 455077). During the war phosphating largely replaced cadmium-, nickel- and chromium-plating, and in many cases galvanising as well. There are now many methods for phosphating zinc or zinc-coated material. Macchia also notes the numerous applications of phosphating in aircraft and aircraft engine construction in Italy, in the motor and cycle industries, and in the manufacture of electrical, telecommunication, shipping, and numerous other fittings. Baths or solutions prepared from the Parker salts, i.e., acid (mono-hydrogen) iron-manganese phosphate, are chiefly used; also the Atramentol process of the I. G. Farbenind. Akt. Ges., using either zinc- or manganese-phosphate. The manufacture of phosphoric acid in Italy, for this and other purposes, was improved and developed. For the Parker salts ferro-manganese is a suitable raw material, containing up to 85% manganese; though it is usually better to

use material of lower manganese content and supplement the supply of that element by adding the desired amount of manganese carbonate derived as a by-product in the manufacture of hydroquinone. Other suitable Italian raw material is pyrolusite, from which the principal impurity, silicon, may be easily removed Zinc phosphate could be prepared from metallic zinc and phosphoric acid, and Italy's supply of this was also assured. For accelerated phosphating, the Bonderite salts were used, consisting of acid iron-manganese phosphate with nitrate accelerators; and this is the method mainly employed in metal drawing work. It should perhaps be pointed out, in connection with metal-drawing and other metal-working processes requiring special lubrication, that the Parker Rust-proof Co. of U.S.A. adapted their Parkerising (phosphating) process, to the special needs of such lubrication, under the name of Lubro-Parkerising, about 1939 or a little earlier. The experimental work of Dürer and Schmidt, referred to above, and of others in Italy and Germany was subsequent to that date.

In regard to Russia, there is not very much information as to practical progress in phosphating; but it was included in one or two papers in the proceedings of the Second Conference on the Corrosion of Metals, at Moscow, in 1943. V. I. Vulphson, for example, reviewed the whole phosphating field fairly thoroughly (*Ibid*, pp. 159–174). A perusal of his paper and some of the others presented at the Conference would seem to indicate that the Russians are not only keenly interested in and well-informed on the work done in other countries; but have also an extensive programme of research of their own, on most forms of metal protection.

The latest issues of the *Jnl. of Applied Chemistry* (U.S.S.R.), received in this country contain many papers on electro-plating and other forms of metal protection; and some on the more theoretical aspects of corrosion. Nor has anodic oxidation by any means been neglected. A small book on "Oxide Coatings on Metals" by Prof. A. G. Samartsev, published in 1944 by the Acad. of Science, Moscow, may be quoted as an example. Though only a booklet of some 100 pp., small 8vo, it contains much material of interest, including a section on anodic oxidation of aluminium, with a brief summary of the author's own views on the, at present, rather controversial subject of anodic film formation and structure.

The Behaviour of the Webs of Plate Girders

By S. R. Sparkes, M.Sc., Ph.D., D.I.C., A.M.I.C.E.

THE work covered in this report was initiated by the former Welding Research Council of the Institute of Welding (now the British Welding Research Association) and forms part of an experimental programme on welded structural steel members and connections which is being carried out under the guidance of the FE.2 Committee on Strength and Rigidity of Welded Structural Connections, of the B.W.R.A.

Theoretical Considerations

Consideration is given in the report to the theoretical aspect of the design of stiffened and unstiffened webs. It is pointed out that the dimensions of webs of plate girders are determined in most cases, when designing to specifications prior to 1946 by the requirements given by the "diagonal column" theory and consequently the limitations specified are often unnecessarily stringent.

The assumption that a web acts as a "diagonal column" takes into account only the principal compressive stress and ignores the complementary tensile stresses which prevent a sudden failure of a "diagonal column" as a strut. Hence the use of a strut formula is regarded as inappropriate for the design of webs, particularly since it gives no indication of the ability of a web to resist buckling.

A mathematical method of estimating limits for web buckling is outlined wherein the web is considered to act as a flat plate appropriately supported at the edges and subjected to suitable conditions of loading. This method, solutions of which have been published by Timoshenko and others, does not, however, take into account either the lack of planeness in a web plate or the unknown degree of fixity between the web and flanges which varies according to the type of construction. It was considered, therefore, that in order to determine how theoretical results are affected by these factors the experimental approach to the problem was the one most likely to give a satisfactory answer.

Experimental Programme

The programme consisted of three series of tests carried out on a total of 24 girder specimens.

The first two series were undertaken with the object of determining the web buckling loads of girders having a constant ratio of web panel length (d) to effective depth of the web (h), but with different h/t ratios (where t = thickness of the web material). In the third series, the specimens for which were of slightly different form of construction, the effect of intermediate stiffeners on webs having different h/t ratios was studied.

A special apparatus was designed to determine the shear yield stress of the web material, and standard tests were made to find Young's Modulus, Poisson's Ratio and the tensile yield stress of the material.

The results of the tests enabled some definite conclusions to be drawn, although the effect of certain variables which were unavoidably introduced in consequence of different methods of construction and differences in the properties of the web material, was not clear in all cases.

Other investigators in this field have commented on the difficulty of deciding when web buckling actually commences and in this respect an interesting fact emerges from the results of the tests. It is stated that in several cases it was possible to show that buckling had taken place, although the behaviour of the girder underwent no sudden change at the buckling load. For design purposes, therefore, the buckling load has little significance and does not adversely affect the load carrying capacity of the girder.

The results of the tests and the conclusions drawn are discussed in relation to the work of other writers, and a number of comparative test results from the earlier investigations of Moore and Wilson, and Lyse and Godfrey are outlined in the appendices.

This report is to be published in the official organ of the B.W.R.A. (the *Welding Research* supplement of the Transactions of the Institute of Welding) for December, 1947, and reprints of this report will also be available on application to the British Welding Research Association, 29, Park Crescent, London, W.1.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

Some Applications of Inorganic Chromatography

By G. Robinson
Chief Chemist, W. Fearnehough, Ltd., Sheffield

(*concluded from p.* 47)

Other Reagents

TWO reagents have been tried for the separation of sodium and potassium[4] which might be worth further study—namely, violuric acid for sodium (red band), and 5-oxo-4-oximino-3-phenyliso-oxazoline (yellow band) for potassium, in each of these cases the original workers diluted the reagent with starch as for 8-hydroxy-quinoline.

Other possible reagents may be found from the following list, all of which seem worthy of further investigation as a means of separating and probably determining the components of metallic mixtures.

(*a*) Sodium diethyl-dithio-carbamate Cu—brown, Bi, Mn, Ni and Co, also Zn—greyish.

(*b*) Diphenylcarbazide Cr (hexavalent) and possibly Co, Cu, Pb and Ni.

(*c*) α–α' Dipyridyl. Mo.

(*d*) Rubeanic acid (Di thio oxamide) Cu, Co, Ni, Ag.

(*e*) Salicylaldoxime. Cu, Ni.

(*f*) Toluene-3-4-dithiol. Ag, Hg, Cd, As, Sb, Pb—Cu, Ni, Co—Sn, Bi, Mo, W, Rh, Pd.

(*g*) Di mercapto-thio-diazole Hg′, Ag, Pb, Sn, Sb, Cu, Hg″, Bi, Pd, Pt, Th, Au.

This reagent also gives coloured complexes with certain metallic anions.

The preceding list of possible reagents is by no means exhaustive and serves only to indicate the vast field of reactions awaiting exploration. Another extensive range of possible interest is those substituted α– and β–naphthols which give coloured lakes with certain metals, for instance, a colorimetric test for traces of copper using the dye Bordeaux " B " has recently been reported[5] which might be adapted to the chromatographic technique. It would seem that inorganic chromatography will prove of greatest service in the field of microchemistry owing to its particular value in detecting mere traces of material. In this respect it might well prove an adjunct to more orthodox methods especially where the amount of sample is strictly limited. That this is so is admirably illustrated by one question recently put to the author, " Would it be possible to take a few milligrams of an unknown steel and produce a chromatogram which would accurately indicate the alloying elements and their approximate amounts ; so enabling a decision to be made as to the analytical procedure to be adopted?" So far, the answer is in the negative, but it is felt that such a procedure ought to be possible and, ultimately, will be possible if the subject were properly investigated. Such an investigation could well be undertaken by a research group or groups who could deal with the problem systematically. Obviously the main difficulty would be removing the iron. This might be possible as the alkaline tartrate complex, but some difficulty could be expected as shown in the experiments with a nickel steel referred to earlier.

Brief mention must be made of a very interesting possible technique.* Since many of the metallic organic complexes are soluble in organic liquids such as chloroform, these solutions, being truly organic in character, should be capable of being adsorbed on a suitable column in the same way as the classical separation of plant pigments was achieved by Tswett and his successors, notably Kuhn.[6] Such a method would have the advantage that the individual zones could be separated from each other by suitable treatment with either the original or a mixed solvent, hence, simplifying any subsequent operations that might be necessary.

In any work on the application of chromatographic methods to inorganic analysis it must be remembered that reproducible results, by whatever method is being used, are absolutely dependent on rigid adherence to uniformity of conditions such as uniformity of packing, salt concentration and pH of the solutions. Any slight variation in any of these factors could completely change the final form of the whole chromatogram. Nevertheless, this very ease of modification will most probably be found to be the means by which any particular group of elements may be separated from each other, since a small change in say pH may cause complete removal of one or more components from the column, so leaving the one required separated from all the others.

4 Erlenmeyer and Schmidlin, *Helv. Chim. Acta*, 1941, **24**, 1213.
5 Alexander, W. A., *Analyst*, 1947, **72**, 56.

6 Kuhn et al., *Z. physiol. Chem.*, 1931, **197**, 141 ; *Ber.*, 1931, **64**, 1349.

* This arises from an idea suggested by Mr. Ronald Belcher, to whom the author is greatly indebted for his interest and encouragement in the work reported here.

Two-dimensional Methods

Another valuable line of approach to the subject may be found in a novel application of chromatography in recent work on quantitative spot tests by Hopf.[7] This method consists in preparing filter papers with either alumina (by precipitation from solution) or starch, followed by impregnation of the prepared paper with a suitable reagent such as 8-hydroxyquinoline. The solution to be tested is spotted on to the paper followed by spots of a suitable wash liquid and concentric zoning of the constituents takes place. From the radii of the coloured circles Hopf found it possible to derive, by Flood's formula[8] an expression which enabled quantitative measurements to be made of the composition of the mixture. One application of this method quoted in the original paper will serve to illustrate the value of this method. Accurate analysis of a ferro-molybdenum steel-making alloy was obtained by spotting on paper suitably prepared with 8-hydroxyquinoline and calculating the ratio between the central yellow spot due to Mo and the outer black ring due to Fe'''.

The present author has repeated these tests with iron and molybdenum and found them highly satisfactory and reproducible, but would like to suggest that the use of alumina and oxine together may restrict the usefulness of what is otherwise a very elegant method. The aluminium hydroxyquinolate formed when the aqueous solution is added, does not influence the central yellow spot due to Mo, but seems to occur solely on the outer edge of the Fe''' zone. It is felt that this might cause some confusion were this method tobe attempted for other pairs of metals.

Inorganic Partition Chromatography

Possibilities in the application of the method of partition chromatography[9] would seem to depend on the use of organic metal complexes which are soluble in organic solvents, and it may be that adsorption in this manner may yield more fruitful results than the direct adsorption on alumina mentioned earlier. The partition method depends for its success upon the use of a column of silica gel, cellulose or starch which hold the more polar phase of a pair of liquids such as chloroform-water mixtures. Synge[10] has referred to the need for research into the use of hydrophobic gel adsorbents in which elution could be effected by the more polar phase of such mixtures, as being a possible advance in the methods used for the chromatography of higher fatty acids and sterols. This also might be of use in the chromatography of metallic complexes. Whether it would be possible to incorporate in the gel adsorbent an organic reagent such as 8-hydroxyquinoline which would act as an "indicator" for metallic ions in an analagous manner to the use of pH indicators for substances of varying pH is another subject worthy of examination.

The foregoing short survey of the general possibilities of this comparatively new analytical technique are admittedly incomplete, yet it is hoped that these few remarks may serve to interest more investigators in what may prove a new and fascinating approach to analytical problems.

7 Hopf, *J.C.S.*, Sept., 1946.
8 Flood, *Tids. Kjemi*, 1937, **17**, 178.
9 Martin and Synge, *Biochem. J.*, 1941, **35**, 91.
10 Synge, *Analyst*, 1946, 71, 256.

A Direct-Reading Microbalance for Preparative Work

By J. T. Stock and M. A. Fill

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THIS apparatus is a development of the larger semi-micro device described elsewhere.[1] It is designed primarily for the rapid weighing of samples in narrow glass tubes, (e.g., melting-point tubes), but can, of course, be used in other directions. The sensitivity may be adjusted within fairly wide limits; in the case of the instrument to be described, a full-scale deflection is obtained for a sample weight of 10 mg. Under these conditions, the maximum error is less than 0·25 mg., so that the device is well suited for micro-preparative work, etc.

A general view of the apparatus without its case is given in Fig. 1. The moving parts are constructed mainly from glass, but no complicated glassworking is involved. No arrestment is used until the load is placed upon the support A at the left-hand end of the beam, the lower extremity of the damping vane B rests on a stop, and no motion of the beam occurs. To prevent interference from draughts, the balance is enclosed in a small case, which is about 20 cm. high, 15 cm. wide and 12 cm. deep. When the balance is to be used, the top of the case is opened, as shown in Fig. 2, thus exposing the beam and counterpoise adjustments.

The centre portion A of the beam assembly (Fig. 9) is constructed from thin-walled 2 mm. bore glass tubing, the arms of the beam consisting of 1 mm. diameter glass rod, and the pointer B of 0·5 mm. diameter glass rod. The extremity of the pointer is drawn out to a point and bent at right angles as shown. Details of the construction of the fulcrum or "knife edge" C are shown in Fig. 9. A melting-point tube is bent twice at right angles to form a flat-bottomed "U." Lengths of 7 mm. are cut from the point ends of two fine sewing needles and are cemented into the arms of the U, as shown. The points of the needles are then thrust into a piece of soft asbestos millboard and the fulcrum is sealed to the underside of the beam-centre by means of a micro-flame. The support provided by the millboard prevents distortion of the fulcrum during the sealing operation. Successful attachment of the fulcrum by fusion is the only operation in the construction in which a little difficulty may be encountered; if such difficulty is experienced, very good results may be obtained by attaching the fulcrum by sparing use of sealing wax. Sensitivity is adjusted in the usual way by raising or lowering the centre of gravity of the beam assembly. This is done by fusing small amounts of glass to the extremity of arm D (Fig. 3).

The points of the needles rest in bearing C (Fig. 1), which is a minute glass trough cemented in a groove cut across the top of the wooden support D. Stages in the construction of the bearing trough are depicted in Fig. 8. A hole is blown in the wall of a length of 3 mm. diameter, 2 mm. bore glass tubing as shown at (A).

1 J. T. Stock and M. A. Fill, *Analyst*, in the press.

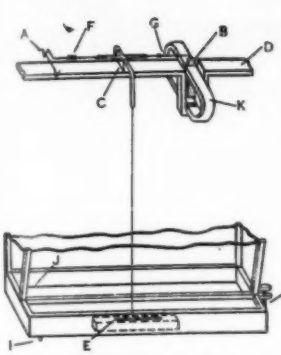

Fig. 1.—Mechanism of balance.

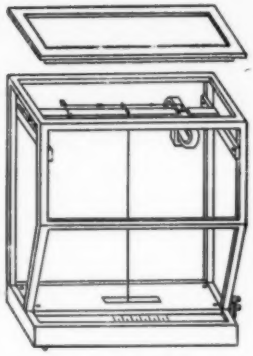

Fig. 2.—General view of balance.

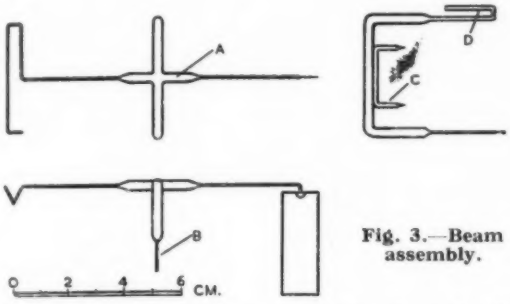

Fig. 3.—Beam assembly.

After heating in the region of the hole, the ends of the tubing are pulled apart as shown (B), when the central portion will be found to have a "U" section. When cold, about 3 cm. is cut out and the ends are fused to form a trough, as shown at (C). The finished bearing trough is very small, as may be judged from Fig. 4, which is a photomicrograph of one of the needle points resting in the trough.

Weighings are observed directly upon scale E (Fig. 1) which is graduated in 0·25 mg. divisions on paper and covered with celluloid. Major adjustments are made by counter-poises F and G, final zeroing being accomplished by the tilting device H, which is fitted to the base of the instrument. The tilting device consists of a knob attached to a short length of 2 B.A. brass screw rod passing through a small screwed plate secured to the underside of the base. The instrument rests upon the extremity of the screw rod and upon the heads of screws I and J, so that rotation of the knob allows the tilt to be varied.

Use of small glass shovels, previously adjusted to a standard weight, was a feature of the semi-micro balance[1] and greatly facilitated weighing operations. The shovels may be scaled down for use with the present balance, but this is troublesome. Use of melting-point type tubes is much preferable. Such tubes are, of course, not uniform in weight, so that counterpoising is necessary.

To decide the probable extent of and variation in counterpoising, lengths of 10 mm. bore glass tubing were drawn out in the usual manner, the narrow central portions cut out and subdivided into equal lengths (about 8 cm.) by nicking with a file in the simple wooden jig shown in Fig. 10. The cut lengths from each draw were then weighed on an ordinary balance, results being as follows :—

TABLE I.—Weights of 78 mm. Lengths of Tubing from Successive Draws

Draw 1	Draw 2	Draw 3
63 mg.	69 mg.	78 mg.
61	67	82
74	70	80
79	85	82
67	77	70
63	68	50
70	60	50
78	62	61
80	60	50
82	57	60
—	68	74
—	80	82
—	94	—
—	109	—
Max variation:		
21 mg.	52 mg.	32 mg.

Accordingly, a counterpoise for about 150 mg., providing an adjustment of somewhat less than 100 mg., should be adequate.

In the previous experiment, the heavy tubes were obvious to the eye and could be easily picked out. To test the efficacy of rapid visual sorting, the cut tubes

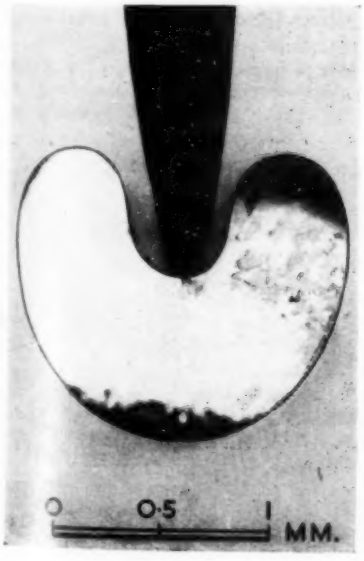

Fig. 4.—Photomicrograph of section of bearing trough.

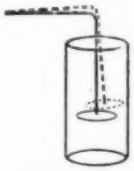

Fig. 7.—Experimental air-damping device.

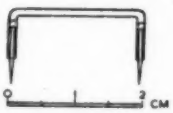

Fig. 9.—Construction of fulcrum.

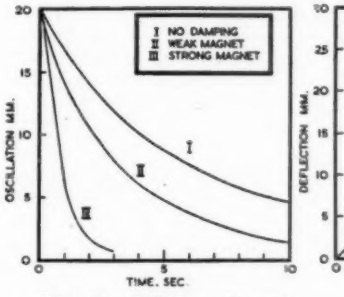

Fig. 5.—Efficacy of magnetic damping.

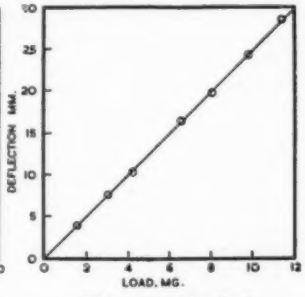

Fig. 6.—Typical calibration curve.

Fig. 8.—Construction of bearing trough.

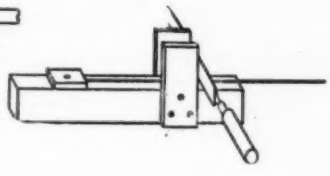

Fig. 10.—Jig for cutting weighing tubes.

TABLE II.—WEIGHTS OF 78 MM. LENGTHS OF TUBING SORTED VISUALLY

Light		Medium		Heavy
67 mg.	....	82 mg.	....	109 mg.
60	....	77	....	94
62	....	74	....	—
50	....	80	....	—
63	....	82	....	—
50	....	80	....	—
70	....	80	....	—
57	....	78	....	—
68	....	79	....	—
69	....	70	....	—
63	....	74	....	—
60	....	82	....	—
70	....	78	....	—
61	....	85	....	—
61	....	82	....	—
68	....	—	....	—
MAX. DEVIATION:				
20 mg.	....	15 mg.	....	15 mg.

from all three draws were bulked together and, using a tube weighing 70 mg. for comparison, were sorted quickly into light, medium and heavy groups as shown in Table II. After sorting, the tubes were reweighed to ascertain the probable weight variation within a group.

Thus if a good stock of weighing tubes is drawn cut to length and rapidly graded as described, the probable variation in weight is not likely to exceed 25 mg.

Various forms of adjustable counterpoise, such as a movable wire rider or a drum-chain device of the "chainomatic" type were considered. Finally, the simple expedient of using two dissimilar pieces of cycle valve rubber, one on each arm of the beam, was adopted. Unlike wire or glass riders, the pieces of rubber which fit very loosely, show no tendency to move under the oscillations of the beam, but their positions may be readily adjusted. The longer (7 mm.) piece of tubing, F (Fig. 1) acts as a coarse adjustment, while the smaller (2 mm.) piece G is normally kept near the middle of the beam and is used for fine adjustment. Both "riders" may be moved without fear of displacing the beam if the tweezers are steadied upon the edge of the case.

The balance has a period of about 2 secs., so that artificial damping is necessary for convenient weighing. Air damping gave a moderate degree of success. A light vane, consisting of a circular microscope cover slip was attached to the end of the beam and operated within a cylinder made from a weighing bottle, as shown in Fig. 7. Owing, however, to the lateral movement of the vane in consequence of its rigid attachment to the beam, the clearance between the vane and the cylinder could not be made small enough to provide heavy damping. Elimination of most of the lateral movement by pivoting the vane support to the beam was considered but rejected as lacking simplicity.

Magnetic damping was then tried with completely satisfactory results, and was adopted. Damping vane B (Fig. 1) is a piece of aluminium foil about 1 cm. wide which is attached to the extremity of the beam and moves in a gap about 2 mm. wide between the poles of magnet K. When in motion, eddy currents induced in the vane rapidly bring the beam to rest. The magnet actually consists of two similar horseshoe magnets assembled North-to-South and facing one another. The requisite gap between one pair of facing poles is maintained by narrow strips of brass so arranged that the vane does not foul them. Damping results using first a pair of old carbon steel magnets and then a pair of small, powerful alloy-steel magnets, are shown in Fig. 5. In the latter case the balance is almost dead-beat.

Initial calibration of the balance was performed by selecting a standard length of tubing, placing it on the support and adjusting the counterpoises until a zero reading was obtained. Short pieces of copper wire, which had previously been weighed on a semi-microbalance of normal design, were successively inserted in the tubing and the corresponding deflections were noted. A typical calibration curve is shown in Fig. 6; within the limits of reading error, the response was found to be linear. Considering the simplicity of the device, reproducibility is excellent. Each point on the calibration curve was determined 10 times and in no case did the greatest and smallest readings of a set differ by more than 0·15 mg. The averages were, of course, used in the construction of the curve.

To check the calibration it is merely necessary to obtain a zero reading with a tube in position and then to insert a 10 mg. piece of wire into the tube or to hang a 10 mg. rider from it.

Results obtained in weighing a typical liquid (nitrobenzene) and a typical powder (naphthalene) are given in Table III. In all cases, the tube containing the sample was repeatedly removed from the support, reversed and replaced until ten readings had been obtained. The true weight was determined by means of a semi-microbalance.

TABLE III.—PERFORMANCE OF BALANCE

Material	True weight	Max. obsd. error*	Reproducibility †	
			Single reading (x)	Mean (y)
	mg.	mg.	mg.	mg.
Nitrobenzene	1·41	0·11	0·067	0·021
	3·20	0·26	0·121	0·038
	5·02	0·13	0·074	0·024
	6·10	0·15	0·066	0·021
	7·91	0·17	0·053	0·017
	9·03	0·10	0·044	0·014
Naphthalene	1·30	0·28	0·083	0·026
	2·41	0·22	0·068	0·021
	3·62	0·03	0·010	0·003
	5·63	0·14	0·047	0·015
	7·39	0·16	0·067	0·021
	10·00	0·17	0·056	0·018

* 10 successive readings.

† $x = \pm \sqrt{\frac{\Sigma \Delta}{n - 1}}$ $\quad y = \pm \sqrt{\frac{\Sigma \Delta}{n(n - 1)}}$

Δ = deviation of individual readings from mean

n = number of readings.

To test the variation in sensitivity with total load, the sensitivity in mm. deflection per mg. was determined by successively using tubes of varying weights, counterpoising each to obtain a zero deflection, and then observing the deflection produced on insterting a 10 mg. wire into each tube. Results are shown in Table IV.

TABLE IV.—VARIATION OF SENSITIVITY WITH TOTAL LOAD

Total Load mg.		Sensitivity mm. per mg.
60	....	2·975
112	....	2·975
160	....	2·950
270	....	2·925

The maximum observed variation of somewhat less than 2% is obtainable only by gross overloading; with weighing tubes drawn in the normal way the variation in sensitivity is insignificant.

Although it is not suggested that the device has the utility and accuracy of a good analytical balance, the cost is very small, construction does not present great difficulties, and weighings can be made directly with considerable speed.

For preparative work performed in capillaries the device is almost ideal.

Aluminium-Silicon Alloys

By Electro-thermal Reduction of Clay with Coke

A Composite

IT may appear a little premature to contemplate the early exhaustion of bauxite supplies in the U.S.A., but whether this apprehension is well grounded or not considerable interest and a certain amount of research have been concentrated on possibilities of utilising the extensive deposits of siliceous clays in various parts of the States. The investigations so far have pursued two main lines: (1) Production of aluminium only; and (2) production of aluminium-silicon alloys. The first was really a war-time measure adopted to counter the serious losses of bauxite by submarine attacks and in view of the supposed rapidly declining bauxite resources of the U.S.A. Since the war it has been continued for this latter reason, although methods used, namely, the hydrochloric acid and the caustic soda processes, are said to be much more costly than using imported bauxite. They have been fully described recently in a publication by the National Bureau of Standards.[1]

The second line of action is the one to be briefly considered here, and appears to hold out much better prospects, technically and economically, than the other. It has been sponsored by the T.V.A. (Tennessee Valley Authority), partly with a view to finding some use for the extensive deposits of siliceous clays which abound in that and adjoining regions; and some of the small scale or pilot plant tests have been described by M. M. Striplin, Jr., and W. M. Kelly,[2] of T.V.A., Wilson Dam, Alabama. The work is not altogether new, for much had already been done in Europe and aluminium-silicon alloys produced from kaolin, alumina, and quartz. The resulting alloys containing 25–70% aluminium and 30–75% silicon, less than 1% iron, and a little titanium, made in electric furnaces, have been used as reducing agents in deoxidising steel, and in the manufacture of Silumin. They are said to be better than ferro-silicon as reducing agent in the production of magnesium from dolomite. There is also the interesting possibility of obtaining pure aluminium from the alloy.[3] Further developments in this field in Germany during the war have been fully dealt with in both British and American investigation reports.

The present work in the U.S.A. was with small scale pilot plants using raw material which abounds in the T.V. and near-by districts, especially pyrophyllite, also bauxitic and kaolin-type clays. Most of the work was done to obtain products for use in steel production rather than for high-purity alloys. From published information it appeared that the most satisfactory procedure was to calcine the ore, mix it with coke or other form of carbon, and feed mixture at frequent intervals into an electric furnace of the arc resistance type, as commonly used for ferro alloys.

In the initial stages of the programme the clay mixture was reduced with coke under various conditions. Attempts to work with excess of carbon beyond the stoichiometrical limits were unsuccessful owing to formation of silicon carbide which seriously interfered with furnace tapping; but with a carbon charge below those limits tapping was much easier. Silicon carbide still accumulated, but was decomposed by occasional addition of more clay or bauxite. Following tables give analyses of some ores used and alloys obtained :—

(a) ORES USED

Ignit. loss	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	
27·6	57·6	9	3·1	2·4	—	Bauxite, Ala.
19·9	49·6	25·2	3·2	1·9	—	" "
14·0	39·9	43·2	0·5	2·3	0·1	Clay, Tenn.
13·8	39·8	45·0	0·3	0·7	0·1	" S.C.
3·9	22·5	73·5	0·1	—	0·1	Pyrophyllite S.C.

(b) ALLOYS OBTAINED

Clay	Bauxite Low Silica	Bauxite High Silica	Silica Rock	Al	Si	Fe	Ti
40			60	23	71	4	2
100		100		45	35	15	5
		100		60	28	10	2
50	50			67	25	6	2
	100			unsuccessful			

Operation of furnace and correlation of electric data are given in some detail in the original. Early in the pilot plant work with 600 kW furnace aluminium-silicon alloy was produced continuously with a power consumption much less than that required when clay was used in the 250 kW furnace; but electrode consumption was high (500 lb. graphite/ton of alloy) compared with electrode consumption earlier reported in the literature for such alloys as a 75% ferro-silicon. Since electrode consumption is usually affected by proportion of carbon in the charge, particle size of reducing agent, and electric conditions, these factors were carefully studied with a view to reducing electrode consumption.

It was found that the optimum carbon content should be 70–75% of stoichiometric, whereby a small quantity of slag was produced with melting point higher than that of the alloy so that it froze in tapping trough whilst the alloy passed. The type of coke used appeared to make little difference. A nine-day run under what were thought to be optimum conditions was made, and results are tabulated. An alloy averaging 51·8 Al, 38·7 Si, 4·9 Fe, and 4·6% Ti was obtained with power consumption of about 5·7 kWh/lb., and electrode consumption of 274 lb./ton alloy. Total recovery of all metals in the ore was 81%, and 2·48 tons calcined clay with 0·72 ton of coke were required per ton of alloy. Aluminium recovery was 90% and silicon 65%. Iron content of alloy was increased by contributions from electrode and tool wear.

Using carbon electrodes, costing only half those of graphite, it was found that no change need be made in the carbon charge, and best electric conditions were 0·33 ohm-in. Changes in resistance affected electrode consumption much more than power con-

1 See also *Engineering*, Sept. 19th and 26th, 1947, pp. 265–6 and 292–3.
2 *Chem. Eng. Prog.*, **43**, 1947, 569–578.
3 Drossbach, *Z.f.Elektrochem.*, **45**, 1939, 534–40 and others.

sumption, and also affected recovery of aluminium and silicon in different degree. With the lowest resistance the alloy contained 50% Al and 41% Si; but with the higher there was more silicon. Under optimum conditions with carbon electrodes the alloy averaged 46·0 Al, 43·8 Si, 4·3 Fe, and 5·9 Ti, with a power consumption of 6·3 kWh/lb., and electrode consumption of 285 lb./ton. Total recovery of all metals was 75%; 2·66 tons calcined clay and 0·87 ton of coke were used per ton of alloy; aluminium recovery was 72% and silicon 67%. About 55% more iron appeared than could be accounted for from the original ore charge. Aluminium vaporised was about 14%, and lost in slag also about 14%.

Comparing these results with ordinary production of ferro-silicon it was found that the aluminium-silicon alloy could be obtained from clay just as easily. No material accumulated in the furnace and carbon lining was satisfactory. The furnace was operated for several weeks without being shut down, cleaned out, or flushed; and any crust formed was not particularly troublesome. Occasionally rather more time was needed for tapping than is the case with ferro-silicon. The same type furnaces could doubtless be used; and power consumption was about the same.

The present process is, therefore, considered promising, and prospects would seem to depend largely on the efficiency of technique employed in using the aluminium-silicon alloy. This alloy had much the same appearance as aluminium and could be cast into pigs for convenience of handling. Also it had a higher capacity for oxygen consumption than other materials commonly used as reducing agents. It is more active, too, than ferro-silicon, owing to its aluminium content. This property could be used to advantage on occasion to obtain higher yields or lower working costs. For use in steel de-oxidation the question is mainly economic. Large scale tests in steel plant have already shown that the alloy is satisfactory for this purpose; and no doubt could be used advantageously in adding silicon to aluminium for this class of alloy. Finally its use for production of pure aluminium, as already hinted, appears worth consideration; and certainly should not be more costly than the chemical methods, using hydrochloric acid or a mixture of caustic soda and common salt.

Resistance of Aluminium Alloys to Fresh Water

By D. W. Sawyer and R. H. Brown

IT is not possible to predict the corrosiveness of a given tap water on aluminium-base alloys from the type of analysis which is ordinarily made on waters. No significant correlation is known between such items as chloride content, sulphate content, total solids, total hardness, total alkalinity, etc., and the corrosiveness of waters on aluminium. It is the presence of minute traces of heavy metals which are not detected by the usual analytical methods, which frequently prevents any correlation between the resistance to corrosion and the constituents normally determined.

Aluminium-base alloys exposed to waters containing certain heavy metals are susceptible to a pitting type of attack, which is accelerated by the presence of chlorides. It has been found that attack on 2S (commercial purity aluminium), 3S (1·2% Mn), 52S (2·5% Mg, 0·25% Cr), 53S (0·7% Si, 1·3% Mg, 0·25% Cr) and 61S (0·25% Cu, 0·6% Si, 1·0% Mg, 0·25% Cr) is not general but localised. In such cases perforations can generally be prevented by using a clad product such as Alclad 3S. Traces of heavy metals in domestic waters of certain districts were found to be responsible for pitting of aluminium cooking utensils. In one instance, for example, ordinary methods of water analysis showed nothing unusual. The water was definitely acidic (pH = 3·8–4·5) and contained 4·4 p.p.m. chlorides and 80–90 p.p.m. total solids. Spectrographic analysis, however, revealed the presence of the following heavy metals:—Copper, 0·09 p.p.m., cobalt, 0·08 p.p.m., nickel, 0·03 p.p.m. Alclad 3S tea kettles have proved remarkably satisfactory in areas where ordinary aluminium kettles had previously suffered from pitting failures.

Neutral or nearly neutral waters having a pH of six to eight have little or no action upon aluminium-base alloys such as 2S, 3S, 4S, 52S, 53S-T, 61S-T and Alclad 3S. This is true even when such waters contain appreciable amounts of chloride, sulphate and bicarbonate ions. For example, when the Aluminium Research Laboratories building was erected in 1929, an aluminium water system was installed. Although several repairs have been made, chiefly on the hot water lines, much of the original aluminium 3S pipe is still in service after a period of 17 years.

A hot water pipe recently removed was found to be in excellent condition. The water in the system has a pH of 7·3 and contains 150 p.p.m. of total solids. Since 1934 Alclad 3S pipe has been used for replacements and to date no failures have occurred with the Alclad 3S pipe. As a general rule, although aluminium alloy 2S, 3S and 4S pipes would be satisfactory for tap water in many localities, Alclad 3S is to be preferred because of the hazard of the presence of heavy metals.

Aluminium-base alloys are generally serviceable for use with waters containing metals of the alkali and alkaline earth groups having a pH range of 8·5–9·0 or below. With some of these waters the pH increases slightly on boiling due to the decomposition of the bicarbonate to carbonate and slight etching may cause staining of aluminium utensils. Staining is an optical effect produced by light absorption resulting from multiple reflection from minute surface irregularities on the etched surface of the metal. The actual amount of attack involved is insignificant, if based upon the weight loss, but is sufficient to give the critical amount of etching required for the darkening of the utensils. The utensils can be brightened by reducing the frequency of the irregularities so as to reduce the number of reflections either by using certain cleaning methods or, in many cases, by continued boiling with one of these waters.

Welded specimens of aluminium alloys 4S–½H, 52S–½H, 61S–W and Alclad 61S–T containing butt welds made with 43S (5% Si) wire have shown encouraging behaviour exposed in the treated water in locomotive tender tanks. The corrosion of the steel of these tanks presents a considerable maintenance problem both from the point of view of the replacement of the corroded steel and from the point of view of the boiler tubes into which the rust gets carried. The water carried in the tender has usually been

Corrosion, 3, September, 1947, No. 9, pp. 443-456.
Abstract from *Light Metals Review*, 6, No. 22, 470-3

treated by the lime-soda process and in a typical case had a pH of 9·1 and total solids (ashed at 500° C.) 195 p.p.m. After eight months' exposure the indications were that the welded aluminium specimens were resistant to this water.

Some alkaline waters with a pH above 8·5 to 9 may be corrosive to aluminium. On the other hand, aluminium has been exposed to solutions which have had a pH higher than 12·5 with practically no attack. Hence, it must be emphasised that pH alone is not a criterion as to the corrosiveness of the water.

Recirculated tap waters have to be given special consideration from the point of view of their possible corrosive action on aluminium. An originally non-corrosive tap water may, on recirculation pick up traces of heavy metals, impurities from surrounding industrial atmospheres or become concentrated by evaporation, all of which may render the recirculated water corrosive. However, if such recirculated waters are maintained nearly neutral by suitable treatment, a suitable corrosion inhibitor such as a chromate may be effective. In some cases where the use of an inhibitor is uneconomical or undesirable it is possible to protect the aluminium parts by means of zinc strips or plates.

Melting High-Speed Steel in the Basic Electric Arc Furnace

By H. C. Bigge

TWO distinct periods characterize the operation of the basic electric arc furnace. The first is an oxidizing period which includes the melt-down of the charge under an oxidizing slag. This lowers the carbon content to the desired point and eliminates excess phosphorus and part of the sulphur. Skimming of this slag is followed by a second, or reducing period, in which a deoxidizing slag (known as white or "falling" slag) is employed.

In the manufacture of 18-4-1 high-speed steel, a single slag is used at Bethlehem Steel Co. First high-speed steel scrap and selected iron-base material are charged, both of known analysis. After calculating the approximate final composition, the major part of the ferroalloys is added, to obtain the advantage of the higher temperature in the melt-down and a more uniform distribution of the tungsten, which, due to its high specific gravity, has some tendency to segregate. Calcium tungstate, when used, is added with the scrap and serves to eliminate part of the carbon and silicon in the charge.

The record of a single-slag 18-4-1 high-speed heat, illustrating the conditions encountered during a heat of this type, is listed. Furnace characteristics are as follows: 7-ton basic electric arc furnace; 3-phase, 25 cycle, 4,000 kva transformer; 12-in. dia. graphite electrodes; magnesite bottom, hearth and side walls; closed pouring spout; removable roof, 9-in. high-alumina brick.

From *Iron Age*, 1947, **160**, No. 16, 118.

The charge was placed in a hot furnace and melted down without addition of reducing agents such as pulverised silicon, pulverised carbon, or calcium carbide. The oxygen in the calcium tungstate (75·61% WO_3 and 21·30% CaO) and in the rust and scale on the surface of the scrap, plays an important part in oxidising the various elements, as clearly indicated by the slag and metal tests given in the attached tables and graphs.

It is also interesting to note the rapid reduction of the alloys in the slag during the slag treatment, as burnt lime, calcium carbide and pulverised carbon are added. This condition is illustrated by coloured photographs of slag samples representing the various conditions from oxidising slag to the reducing slag of the white, "falling" type.

Table I lists the material charged, while Table II gives the difference in the analysis of the melt-down slag and the final ladle slag. An interesting comparison is given in Table III, which shows a rather remarkable agreement between the estimated and the actual analyses of the metal.

The practice followed in obtaining the results as indicated in the furnace log sheet, was as follows: Moulds heated to 300° F.; moulds smoked with rosin for 45 secs.; hot tops heated to 1,200° F.; temperature of ladle, 1,200° F.; tapping temperature of metal, 2,900° F. (immersion thermocouple); metal held in ladle 16 min. The furnace spout has a diameter of 3½ in., and the ladle nozzle 1 in. Copper stools were used in all of the moulds.

In order to obtain best efficiency in the reactions between metal and slag (and metal and furnace additions) the heat is rabbled repeatedly. A total of eight manual rabbling operations are performed in the course of a typical heat, starting before the charge is melted, and performed at intervals until just prior to tapping. The total time required for the heat, from tap to tap, was 6 hrs. 55 mins., of which 2 hrs. 15 mins. involved charging to melting, 1 hr. 45 mins. melting time and 2 hrs. 45 mins. operating under a deoxidising bath.

A total of 5,900 kw-hr. was consumed, resulting in 766 kw-hr. per net ton of ingots. Upon completion of pouring each ingot, the hot top was covered with an insulating material.

As is shown in further tables, the total gross weight of the charge was 16,940 lb. and the metal weight, 15,874 lb. The metal recovered was 15,410 (a loss of 464 lb.), representing a metal recovery of 97·07%. The recovery of alloys is high, except that of chromium, for which the figure is only 92·77%. The chromium content of the slag is correspondingly high, which may be due to a loss of chromium during the melt-down, by oxidation at the high temperature of the arc.

TABLE I.—HIGH-SPEED STEEL HEAT

Material Charged	Gross Weight, Lb.	Metallic Weight, Lb.
Burnt lime	200	—
18-4-1 scrap	7,137	7,137
Calcium tungstate ($CaWO_4$)	800	480
Ferrotungsten	1,346	1,346
High-carbon ferrochrome	500	500
Low-carbon base metal	5,932	5,932
Total Charge	15,915	15,395

TABLE II.—SLAG ANALYSIS

Slag Analysis, %	Melt Down[1]	Ladle[2]
MnO	1·61	0·10
P_2O_5	0·03	0·05
FeO	3·68	0·14
Fe_2O_3	5·90	0·09
Cr_2O_3	17·41	0·06
WO_3	8·87	None
V_2O_5	6·68	0·18
CaO	23·52	55·77
SiO_2	10·20	26·80
CaF_2	11·54	5·12
CaS	0·11	0·72
CaC_2	0·16	0·75
Al_2O_3	3·83	3·98
MgO	5·82	7·17
$CaO-SiO_2$ ratio	2·30	2·08

1 Slag—black, solid.
2 Slag—white, powder.

TABLE III.—METAL ANALYSIS

	Analysis of Charge, (Aim), %	Estimated Analysis of Charge, %	Analysis Melt Down, %	Analysis Final Ladle, %
C	0·795	0·55	0·46	0·73
Mn	0·30	0·15	0·08	0·30
P	0·020	0·020	0·021	0·018
S	0·032	0·031	0·026	0·010
Si	0·46	0·27	0·17	0·18
Cr	4·29	4·08	3·26	4·10
W	18·59	18·58	17·96	18·68
V	1·15	0·48	0·37	1·17

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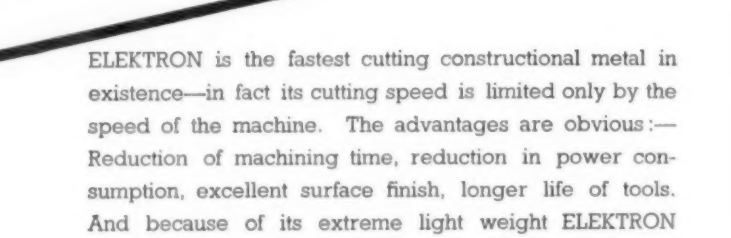

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Flash Welding Theory and Practice

By W. H. Cockran

FLASH-BUTT welding is probably the one process that has been accepted by engineers and production men, without question, for a number of years. It is extremely reliable, and if a few reasonable precautions are taken, very few difficulties are encountered. As the name implies, flash-butt welding is a means of making butt welds and is classified under the resistance welding processes. Upset-butt welding, also a type of resistance butt-welding, has certain limitations. It is not as efficient, for instance, for welding large sections, because the size of equipment involved requires more preparation, and so does not have as wide a general field of application as flash-butt welding. Upset-butt welding, therefore, has been relegated to the field of very special applications.

All flash welding operations are similar in that they have the heating or flashing cycle, which is sometimes preceded by a preheating period, the flashing cycle being followed by the upsetting period which in turn may be followed by a post-heating cycle. All flash welding applications do not require all these cycles of heating, and all machines are not equipped to perform all of them. The only two cycles that are identified with all flash welding applications are the flashing and upsetting.

The heat in flash welding is generated when the parts to be welded are clamped and the current passed through with sufficient material overhanging the dies to allow for burn-off and upset.

The pieces to be welded are brought together slowly under light pressure, with the welding transformer energised so that there is an electrical potential between the two parts. As these two parts touch, there is localised heating between the touching irregular surfaces which raises these surfaces to a temperature above the melting point. This molten metal is expelled in the form of sparks, and the burning away of the high spots of the irregular surfaces, causing the arcing area to be increased and the flashing to be intensified.

While this metal is being expelled and more arcs are being formed, the parts are continually moving together so as to maintain the flashing gap. As more and more arcs are formed and as metal is being burned off and the flashing action increased, heat is progressively generated back of the flashing area. When this area extends far enough and the correct temperature is reached, the parts are moved quickly together and the weld is made.

Allowing the current to flow for a short period during the upset time insures a cleaner weld with less voids. The length of time the current is allowed to flow during the upset period is determined by the cross-section being welded. The greater the cross-section area, the longer the current may flow during the upset. If the time the current flows during the upset is unduly prolonged, the weld may be partly burned and the resulting bond may be weak.

The speed of upset is very important and cannot be overemphasised. When welding such alloys as aluminium, proper control of the speed of upset is essential to the success of the weld. While the flashing period serves the purpose only of heating the parts to be welded to a temperature in the plastic range, the time of flashing is closely related to the area to be welded. Obviously the energy of heating might be applied in either a short or a long time.

In welding heavy sections, a high flashing rate or high energy input allows the heat to be lost rapidly by radiation, and does not allow the heat time to conduct into the work back of the flashing area. Such welds may be more critical to make, and lack of subsequent increased plastic area may cause more voids and unfused areas than a weld made with less energy and at a slower rate.

When welding thin sections, a prolonged heating period may cause the heated area to become too large, and the thin section may buckle when the upset pressure is applied. As a general rule, heavy sections are welded at a slow enough rate to allow the heat to soak back of the flash, and thin sections are welded at a fast rate with a narrow range of heated area.

There is also another essential that enters into the technique of flash welding, namely, material overhang. As the flash-welding dies are water-cooled, and as the resistance of the material that overhangs the dies generates some heat, too little or too much overhang may affect the weld. The material overhang is not too important when welding heavy material as long as the overhang is sufficient for the burn-off and upset; heavy sections can support themselves readily. However, when flash welding thin sections, if too great a material overhang is used, the material will buckle when the weld is upset.

From *Iron Age*, **160**, 1947, No. 16, 150.

Concentration of Manganese from Molten Spiegebisen in a Sulphide-Oxide Slag

By Helge Löfquist

A PREVIOUS method for concentrating manganese from low-percentage iron-manganese alloys into a sulphide-oxide slag of low melting point (1,300° C.) has been further developed. Mn-rich equilibrium slags have been produced in a more rapid and effective way by blowing the slag-forming substances containing S and O from the bottom into the molten alloy, with the view of increasing the reaction interface. The experiments have been made with 230 kg. molten alloy in a basic lined 50 kW arc furnace (Rennerfelt-type). The following slag-forming substances have been used: SO_2 gas alone and mixed with fine pyrite concentrate, pyrite concentrate blown in with air, concentrates of pyrite and of magnetite blown in with air or nitrogen. Slags with compositions corresponding to real equilibria with the Mn-containing alloys have been obtained by using SO_2 + pyrite and almost the same result has been obtained by using pyrite + air. Pyrite + magnetite blown in by air or by nitrogen have given slags with Mn contents approaching to equilibrium, but their Fe contents were slightly too high. SO_2 gas gave a very slow formation of slag as compared to slagging by means of the more concentrated S and O carriers, pyrite and magnetite. It seems to be most convenient to blow in pyrite concentrate with a controlled amount of air, where by the nitrogen left blowing through the furnace protects the slag layer against oxidation of S. This method was found to give, with high yields of Mn and of S, slags containing 60–65% Mn; 3–5% Fe; 3% SiO_2; 16–18% S, being fluid at 1,350–1,400° C.

From *Jernk. Annal.*, 1947, **131**, 493–516.

Die Castings that Cost less than Screw Machine Products

By Herbert Chase

WAR experience, especially in the manufacture of fuse and similar parts, taught many manufacturers that die castings often yield a product costing less than can be turned out by the automatic screw machine. Actually, the basic facts were well established long before the war and they apply, of course, to a far greater number and variety of parts than were required for war-time products.

In common with all machines, the screw machine has its limitations. Where these are controlling or where the die casting machine or some other machine offers a better balance of advantages over limitations, they are the logical ones to employ.

Basically, the automatic screw machine is limited to the use of bar or tubular stock, although it can be operated as a chucking machine if loaded by hand or by a magazine loading device. This chucking possibility is recognised but not often used. For simplicity in this discussion, chucking possibilities are omitted, but it is worth remembering that the automatic screw machine can be converted to a chucker and then even can be used effectively to machine die castings.

Because the automatic screw machine must use bar or tubular stock, it often creates a vast waste in chips. Virtually all its operations involve cutting and what is cut away is largely wasted although often having scrap value. This gives the die casting machine an important advantage because, although its product, as cast, involves considerable scrap, this scrap is immediately remelted and reused with only very minor loss.

Another disadvantage of the automatic screw machine is that it produces only surfaces of rotation, generally about one axis. Moreover, the time required for many cuts is quite long. In consequence, the shape of parts is limited and production is not always rapid. The die casting machine is not confined to making surfaces of rotation. In general, it can perform the equivalent of the secondary operations; such as forming flats, slots or cross holes, or shaping both ends of the part. These operations, when done by the screw machine, necessitate transfer devices and attachments but often make necessary the use of a secondary machine if the basic part is made on the screw machine.

It is of even greater importance that the die casting machine shapes its product almost instantaneously. Some dwell follows the filling of the die to permit the casting to freeze and harden enough for ejection, but the cycle is a fast one. Often several parts, either duplicates or different, are made in each cycle. These are exceedingly important advantages and often are the controlling ones in giving the die casting preference.

But the die-casting machine also has its limitations. It uses only non-ferrous alloys and not a very wide range of these. About 75% of die-casting tonnage is in one of two zinc alloys. Around 20% is in three or four aluminium alloys. Most of the remainder is in copper alloys, chiefly brasses, although some castings are based respectively on magnesium, lead or tin. No ferrous alloys are used in die casting.

Tooling for the die-casting machine generally costs much more than for the screw machine, but when secondary operations are needed on screw machine products, the difference is decreased and may even favour the die casting. Lower tooling costs often favour the screw machine product but, as quantities increase the allowances for regrinding and resetting screw machine tools are made, the die casting generally gains in relative advantages.

With regard to dimensional accuracy and finish, the factors are numerous and generalisations can be misleading. Each process has limitations and advantages. Each have advantages the other does not possess. Most die castings need some machining, but only light cuts are commonly required. The cost of such machining is always added to piece cost, but total cost of the wide range of examples illustrated in the original article is presumed to be lower than the equivalent screw machine products, otherwise purchasers would not have chosen the die-cast product.

From *Materials and Methods*, 1946, **26**, No. 4, 90–94.

Experimental Furnace

A REBUILT 122-ton open-hearth furnace at the South Works of Carnegie-Illinois Steel Corporation, a subsidiary of United States Steel Corporation, located in South Chicago, Illinois, features the use of basic refractories for all parts of its masonry construction exposed to high temperatures, with the exception of the walls and roofs of the checker chambers, the checker brick, floors and bulkheads of the slag pockets, and the roofs of the fantails.

Designed as an experimental furnace for use under commercial conditions to determine the economic and metallurgical advantages obtainable from a basic lining, it will also be used to study the application of oxygen as a combustion supplement. In addition, it will provide an opportunity for comparing the characteristics of various kinds of refractories. Experiments will include the use of oxygen in different kinds of burners, and the use of preheated compressed air for atomisation of oil.

All available data relating to the use of basic refractories in open-hearth furnace construction were carefully studied and correlated to evolve a furnace design appearing to offer the simplest and safest solution to the various problems inherent in the use of basic brick. By using refractories of the same nominal types, but from different sources, it is intended to compare the characteristics of the several types as influenced by their compositions and methods of manufacture. This part of the investigation was furthered by using similar brick from different sources in comparable parts of the furnace.

Basic refractory brick and shapes used in building the masonry of the furnace were obtained from three independent sources and comprise five kinds. They include metal-encased and plain chrome-magnesite brick of the chemically bonded type; burned chrome-magnesite brick, some of which are encased in metal after burning and some intended for use with loose metal plates. In addition to the basic brick there are two grades of firebrick—a double-burned super-duty brick, and a first-quality fire-brick. Insulating brick is also employed along with insulating cement and concrete that serve the double purpose of insulating and sealing masonry surfaces.

From *Mech. Eng.*, **69**, 1947, 941–2.